CHAPTER 7

FLATHEAD SOLE

by

Paul D. Spencer, Gary E. Walters, and Thomas K. Wilderbuer

EXECUTIVE SUMMARY

The following changes have been made to this assessment relative to the November 2001 SAFE:

Changes in the input data

1) 2002 total catch and discards through 21 September, 2002.
2) 2002 trawl survey biomass estimate and standard error.
3) 2002 length composition of the survey abundance.
4) 2001 length composition of the fishery catch.
5) Re-estimated age-length transition matrices and weights at age, based upon survey data.
6) In previous assessments, the survey age compositions were combined across sexes. In this assessment, separate survey age compositions for each sex were used.

Model results

1) Estimated 3+ total biomass for 2003 is 549,983 t.
2) Projected female spawning biomass for 2003 is 224,526 t.
3) Recommended ABC for 2003 is 66,410 t based on an $F_{40\%}$ (0.29) harvest level.
4) 2003 overfishing level is 80,563 t based on a $F_{35\%}$ (0.35) harvest level.

The following summarizes our recommendations for flathead sole fisheries conservation measures.

	2001 Assessment recommendations for the 2002 harvest	2002 Assessment recommendations for the 2003 harvest
ABC	82,572 t	66,410 t
Overfishing	100,770 t	80,563 t
F_{ABC}	$F_{0.40} = 0.30$	$F_{0.40} = 0.29$
$F_{overfishing}$	$F_{0.35} = 0.38$	$F_{0.35} = 0.35$

INTRODUCTION

The flathead sole (*Hippoglossoides elassodon*) is distributed from northern California, off Point Reyes, northward along the west coast of North America and throughout Alaska (Hart 1973). In the northern part of its range it overlaps with the related and morphologically similar Bering Flounder (*Hippoglossoides robustus*) whose range extends north to the Chukchi Sea and into the western Bering Sea. The two species are very similar morphologically and at-sea identification is extremely difficult on the production schedule of the annual trawl survey. However, we feel there has been increasing accuracy during recent years. The growth and distribution differences between the species were described in Walters and Wilderbuer (1997), which illustrated the possible ramifications of combining information. For the purposes of this section, these two species are combined under the heading, *Hippoglossoides* sp.

Hippoglossoides sp. are managed as a unit stock in the Bering Sea and Aleutian Islands and were formerly a constituent of the "other flatfish" SAFE chapter. In June 1994, the Council requested the Plan Team to assign a separate ABC for flathead sole (*Hippoglossoides* sp.) in the BSAI, rather than combining flathead sole (*Hippoglossoides* sp.) with other flatfish as in past assessments. This request was based on a change in the directed fishing standards to allow increased retention of flatfish.

DATA

Commercial Catch Data

Catch Biomass

Prior to 1977, catches of *Hippoglossoides* sp. were combined with the species of the "other flatfish" category, which increased from around 25,000 t in the 1960s to a peak of 52,000 t in 1971. At least part of this apparent increase was due to better species identification and reporting of catches in the 1970s. After 1971, catches declined to less than 20,000 t in 1975. Catches from 1977-89 averaged 5,286 t increasing to an annual average of 17,916 t from 1990-2001 (Table 1). The resource remains lightly harvested as the 2002 catch through 21 September is only 65% of the 2002 TAC of 21,250 t. The catch of flathead sole taken in research surveys from 1979-2001 are shown in Table 2. The catch locations by quarter for 2001 for flathead sole hauls (defined by flathead sole contributing at least 20% of the total catch) are shown in the Appendix.

Although flathead sole (*Hippoglossoides* sp.) receive a separate ABC and TAC they are still managed in the same PSC classification as rock sole and "other flatfish" and receive the same apportionments and seasonal allowances of bycaught prohibited species. In recent years, the flathead sole fishery has been closed prior to attainment of the TAC due to the bycatch of halibut (Table 3).

Substantial amounts of flathead sole are discarded overboard in various eastern Bering Sea target fisheries. Retained and discarded amounts are estimated for recent years using observer estimates of discard rate applied to the “blend” estimate of observer and industry reported retained catch (Table 4). A substantial portion of the discards in 2001 occurred in the Pacific cod, pollock, and rock sole fisheries.

Fishery Catch and Catch-at-age Data

This assessment uses fishery catches from 1977 through 21 September, 2002 (Table 1), and estimates of number caught by length group and sex for the years 1977-2001 (Tables 5-6).

Survey Data

Survey Biomass

Because *Hippoglossoides* sp. is often taken incidentally in target fisheries for other species, CPUE from commercial fisheries seldom reflect trends in abundance for these species. It is therefore necessary to use research vessel survey data to assess the condition of these stocks.

Survey estimates of total biomass and numbers by length group and sex for the years 1982-2002 are shown in Tables 7-9 and Figure 1. The survey gear changed after 1981, and as in previous assessments (Spencer et al. 1999) only the data from 1982 to the present are used. Since the early 1980s, estimated *Hippoglossoides* sp. biomass has approximately quadrupled to the 1997 peak estimate of 807,825 t (Figure 2). However, estimated biomass declined to 394,822 t in 1999 and 399,298 t in 2000, respectively, and increased to 574,946 t in the 2002 survey.

Survey age composition

In previous assessments, age composition data from the survey was combined across both sexes. Given the differential growth curves across sexes and the split sex nature of the model (described below), age composition data by sex was used in this assessment.

In summary, the data available for flathead sole are

1) Total catch weight, 1977-2002;
2) Proportional catch numbers by length group, 1977-2001;
3) Survey biomass and standard error, 1982-2002;
4) Survey age composition 1982, 1985, 1992, 1995, and 2000;
5) Proportional survey numbers by length group, 1983-1984,1986-1991,1993-1994,1996-1999, and 2001-2002.

ANALYTIC APPROACH

Model Structure

The assessment model has a length-based formulation, which is underlaid by an age-based model. A transition matrix (**TR**) is used to convert the selectivity at length to selectivity at age, and to convert the predicted catch and numbers at age to catch and numbers at length.

An age-structured, split-sex population dynamics model was used to obtain estimates of recruitment, numbers at age, and catch at age for each sex. Population size in numbers at age *a* in year *t* for sex *s* was modeled as

$$N_{s,t,a} = N_{s,t-1,a-1} e^{-Z_{s,t-1,a-1}} \qquad 4 \le a < A, \quad 2 \le t \le T$$

where Z is the sum of the instantaneous fishing mortality rate ($F_{s,t,a}$) and the natural mortality rate (M_s), A is the maximum number of ages in the population, and T is the terminal year of the analysis (2001). The numbers at age A are a "pooled" group consisting of fish of age A and older, and are estimated as

$$N_{s,t,A} = N_{s,t-1,A-1} e^{-Z_{s,t-1,A-1}} + N_{s,t-1,A} e^{-Z_{s,t-1,A}}$$

The total numbers of age 3 fish over all years are estimated as parameters in the model, and modeled with a lognormal distribution

$$N_{t,3} = e^{(\mu_R + \nu_t)}$$

where ν is a time-variant deviation. The number of recruits is divided equally between males and females. The numbers at age in the first year are modeled to be in equilibrium with an historical catch of 1500 t, and requires estimation of a historic recruitment parameter (R_0) and a historic fishing mortality rate (f_{hist}).

The fishing mortality rate for a specific age and time ($F_{t,a}$) is modeled as the product of a fishery age-specific selectivity function (*fishasel*) and a year-specific fully-selected fishing mortality rate f. The fully selected mortality rate is modeled as the product of a mean (μ_f) and a year-specific deviation (ϵ_t), thus $F_{t,a}$ is

$$F_{t,a} = fishasel_a * f_t \equiv fishasel_a * e^{(\mu_f + \varepsilon_t)}$$

The fishery selectivity at age is obtained from the selectivity at length and the transition matrix $\mathbf{TR_s}$, where the transition matrix $\mathbf{TR_s}$ indicates the proportion of each age (rows) in each length group (columns) for each sex; the sum across each age is equal to one. Because of growth differences between the sexes, there is a separate transition matrix and age –based selectivity vector for each sex; these matrices were computed as described above. The selectivity at age vector is computed from the fishery selectivity at length vector (**fishlsel**) as

$$\mathbf{fishasel_s} = \mathbf{TR_s} * \mathbf{fishlsel}$$

Finally, the selectivity at length vector, assumed identical for each sex, was modeled as

$$fishlsel_l = \frac{1}{1 + e^{-slope(l - fifty)}}$$

where the parameter *slope* affects the steepness of the curve and the parameter *fifty* is the length at which $fishlsel_l$ equals 0.5. There are 24 length bins ranging from 6 to 58 cm, and 19 age groups ranging from 3 to 21+. The age- and length-based selectivity for the survey is modeled in a similar manner.

The mean numbers at age for each year and sex were computed as

$$\overline{N}_{s,t,a} = N_{s,t,a} * (1 - e^{-Z_{s,t,a}}) / Z_{s,t,a}$$

The transition matrix and vector of mean numbers at age were used to compute the vector of mean numbers at length, by sex and year, as

$$\overline{\mathbf{NL}}_{s,t} = \overline{\mathbf{NA}}_{s,t} * \mathbf{TR}_s^{\mathbf{T}}$$

The vector of mean numbers at length was used to compute the catch as

$$C_{l,s,t} = \overline{NL}_{l,s,t} * fishlsel_l * f_t$$
$$pred\_cat_t = \sum_{l,s} C_{l,s,t} * FW_{l,s}$$

where $FW_{l,s}$ is the fishery weights by length and sex, and *pred_cat* is the predicted catch from the model. Similarly, the predicted survey biomass (*pred_biom*) is computed as

$$pred\_biom_t = qsurv \sum_{l,s} \left(\overline{NL}_{l,s,t} * survlsel_l * PW_{l,s} \right)$$

where $PW_{l,s}$ is the population weight by length and sex, and *qsurv* is the trawl survey catchability.

Parameters Estimated Independently

The parameters estimated independently include the age error matrix, the transition matrix, individual weight at length, natural mortality, and survey catchability (*q_srv*).

Aging error

Age composition data are assumed to be unbiased, but with some aging error. The distribution of read ages around the "true" age is assumed to be normal with a coefficient of variation of 0.14, as in previous assessment of flathead sole with the stock synthesis model (Walters and Wilderbuer 1998). The vector of mean number of fish by age available to the survey is multiplied by the aging error matrix in order to produce the observed survey age compositions.

Trawl survey selectivity

The trawl survey selectivity, *qsurv,* was fixed at 1.0 consistent with recent assessments (Walters and Wilderbuer 1998).

Natural mortality

M was fixed at 0.2 consistent with recent assessments (Walters and Wilderbuer 1998).

In the 2001 assessment, an evaluation of growth rates from the survey data was presented and it was concluded that the transition matrices should be updated to reflect the new growth curves (Spencer et al. 2001). The 2002 assessment model includes the updated transition matrices. A comparison of the underlying length-at-age relationships in the old and new transition matrices is shown in Figure 2.

Weight at age

In this assessment the individual weights at age were obtained from trawl survey data. In previous assessments, the weight at age in the fishery catch was assumed to differ from the population weight at age. This assumption was checked by comparing the growth rates obtained from the fishery data to those obtained from the survey data. From the fishery, a total of 599 female and 388 male otoliths, sampled in 1994, 1995, 1998, and 2000, have been read. In contrast, 1148 male and 1371 female otoliths from the survey data have been read. Based upon Akaike's information criterion, the fishery female growth curve is not significantly different from that obtained from the survey data (Figure 3). The male fishery growth curve does differ significantly from the male survey growth curve. However, the asymptotic length in both curves is similar and most of the difference comes at ages less than 9, where there are limited fishery otoliths. Due to the selectivity patterns of the fishery, only 26 otoliths per sex for ages 8 or less have been sampled. It was concluded that the available fishery data did not provide clear evidence of a length-at-age pattern different from the survey data, and the survey growth curves were used for the fishery weights.

Length- weight

A length (cm) – weight (g) relationship of the form $W = aL^b$ was also fit to *Hippoglossoides* sp., with the estimated parameters of a = 0.00326 and b = 3.3 applying to both sexes.

Parameters Estimated Conditionally

Parameter estimation is facilitated by comparing the model output to several observed quantities, such as the age compositions of the survey, length composition of the fishery and survey catches, the survey biomass, and the catch biomass. The general approach is to assume that deviations between model estimates and observed quantities are attributable to observation error and can be described with statistical distributions. Each data component provides a contribution to a total log-likelihood function, and parameter values that minimize the log-likelihood are selected.

The log-likelihood of the initial recruitments were modeled with a lognormal distribution

$$\lambda_1\left[\sum_t \frac{\left(\nu_t + \frac{\sigma^2}{2}\right)^2}{2\sigma^2} + n\ln(\sigma)\right]$$

where σ is a parameter representing the standard deviation of recruitment, respectively, on a log scale. The adjustment of adding $\sigma^2/2$ to the deviation was made to correct for bias and produce deviations from the mean, rather than the median, recruitment.

The log-likelihoods of the fishery and survey age and length compositions were modeled with a multinomial distribution. The log of the multinomial function (excluding constant terms) for the fishery length composition data, with the addition of a term that scales the likelihood, is

$$n_{f,s,t,l}\sum_{s,t,l} p_{f,s,t,l}\ln(\hat{p}_{f,s,t,l}) - p_{f,s,t,l}\ln(p_{f,s,t,l})$$

where n is the number of fish aged, and $p_{f,s,t,l.}$ and $\hat{p}_{f,s,t,l}$ are the observed and estimated proportion at length in the fishery by sex, year and length. The likelihood for the age and length proportions in the survey, $p_{surv,s,t,a}$ and $p_{surv,s,t,l}$, respectively, follow similar equations.

The log-likelihood of the survey biomass was modeled with a lognormal distribution:

$$\lambda_2\sum_t(\ln(obs\_biom_t) - \ln(pred\_biom_t))^2 / 2cv_t^{\,2}$$

where obs_biom_t is the observed survey biomass at time t, cv_t is the coefficient of variation of the survey biomass in year t, and λ_2 is a weighting factor.

The log-likelihood of the catch biomass was modeled with a lognormal distribution:

$$\lambda_3\sum_t(\ln(obs\_cat_t) - \ln(pred\_cat_t))^2$$

where obs_cat_t and $pred\_cat_t$ are the observed and predicted catch. Because the catch biomass is generally thought to be observed with higher precision that other variables, λ_3 was given a very high weight so as to fit the catch biomass nearly exactly. This can be accomplished by varying the F levels, and the deviations in F are not included in the overall likelihood function. The overall negative log-likelihood is

$$\begin{aligned}
&\lambda_1\left(\sum_t\left(\frac{(\nu_t+\sigma^2/2)^2}{2\sigma^2}\right)+n\ln(\sigma)\right)+\\
&\lambda_2\sum_t(\ln(obs_biom_t)-\ln(pred_biom_t))^2/2*cv_t^2+\\
&n_{f,s,t,l}\sum_{s,t,l}p_{f,s,t,l}\ln(\hat{p}_{f,s,t,l})-p_{f,s,t,l}\ln(p_{f,s,t,l})+\\
&n_{surv,s,t,a}\sum_{s,t,a}p_{surv,s,t,a}\ln(\hat{p}_{surv,s,t,a})-p_{surv,s,t,a}\ln(p_{surv,s,t,a})+\\
&n_{surv,s,t,l}\sum_{s,t,a}p_{surv,s,t,l}\ln(\hat{p}_{surv,s,t,l})-p_{surv,s,t,l}\ln(p_{surv,s,t,l})+\\
&\lambda_3\sum_t(\ln(obs_cat_t)-\ln(pred_cat_t))^2
\end{aligned}$$

For the model run in this analysis, λ_1, λ_2, and λ_3 were assigned weights of 1,2, and 500, respectively, and n was set to 200. The likelihood function was minimized by varying the following parameters:

Parameter type	Number
1) fishing mortality mean (μ_f)	1
2) fishing mortality deviations (ϵ_t)	26
3) recruitment mean (μ_r)	1
4) recruitment standard deviation (σ)	1
4) recruitment deviations (ν_t)	26
5) historic recruitment (R_0)	1
6) historic fishing mortality (f_{hist})	1
7) fishery selectivity parameters	2
8) survey selectivity parameters	2
Total parameters	61

RESULTS

Biomass trends

The model results show that estimated total biomass (ages 3+) increased from a low of 147,395 t in 1977 to a peak of 802,677 t in 1993 (Figure 3, Table 10). Since 1991, estimated total biomass has declined to an estimated value of 538,042 t for 2002. Female spawning biomass shows a similar trend, although the peak value (336,783 t) occurred in 1996 (Figure 3). The estimated survey biomass shows an increase from 1982 to the peak level of 580,180 t in 1994, and a subsequent decline to 409,486 t in 2002 (Figure 5). The model fits the survey biomass time-series well during the period of increasing biomass, but provides a poor fit to the 1994, 1997 and 1998 estimates, when it indicates a population decline while survey biomass estimates remain high. The continued trend of declining estimated biomass since the early 1990s results in the estimated 1999 and 2000 survey biomass matching the observed biomass more closely than the estimated 2001 and 2002 biomass matches the observed biomass (Figure 5). The model provided a good fit to the survey size compositions for the past 10 years for females and males as shown Figures 6 and 7. Reasonable fits also resulted for fishery size composition observations (Figures 8 and 9) and the survey age composition (Figures 10 and 11).

The overall decrease in stock biomass relative to the 2001 assessment (Table 10) is due to updating the transition matrices. Recall that numbers at length are produced within the model by multiplying a numbers at age vector by the transition matrix. For a given numbers at age vector, the new matrices will produce fewer fish in the smaller length bins and more fish in the larger length bins. To obtain good fits to the length composition data, the recruitment estimates are adjusted to produce fewer fish at the older ages. The survey biomass estimate is similar to the model with the previous transition matrices because the survey selectivity is raised to adjust for decreased numbers of fish, but the total biomass and spawner biomass are lower.

Recruitment trends

The changes in stock biomass are primarily a function of recruitment, as fishing pressure has been relatively light. The fully selected fishing mortality estimates remain small, and have averaged 0.05 from 1990 to 2001 (Figure 12), and the fishery shows little selectivity for flathead sole less that 30 cm (Figure 13). Estimated recruitment at age 3 has generally been higher during the early portion of the data series, averaging 8.5×10^8 for the 1975-1988 year classes, and 4.0×10^8 for the 1989-99 year classes (Figure 14). The scattterplot of stock and recruitment data reveals a decreasing trend in recruitment with an increasing trend in spawner biomass (Figure 15). The survey size composition from 1994-2001 indicates that the proportion of fish at smaller sizes is reduced from the high recruitment years of the 1980s, leading to the decline in estimated biomass.

The extent to which the density-dependence observed in the scatterplot of spawer-recruit data (Figure 15) is affected by environmental conditions is unresolved (Wilderbuer et al., in press). For example, a series of high spawner stock biomasses and low recruitments were observed for the post-1988 year classes, coinciding with changes in the environmental indices such as the Aleutian low pressure index (Overland et al 1999, Hare and Mantua 2000). Stock-recruitment analyses that consider this environmental variability are a priority for future flathead sole research.

PROJECTIONS AND HARVEST ALTERNATIVES

The reference fishing mortality rate for flathead sole is determined by the amount of reliable population information available (Amendment 56 of the Fishery Management Plan for the groundfish fishery of the Bering Sea/Aleutian Islands). Estimates of $F_{0.40}$, $F_{0.35}$, and $SPR_{0.40}$ were obtained from a spawner-per-recruit analysis. Assuming that the average recruitment from the 1977-1999 year classes estimated in this assessment represents a reliable estimate of equilibrium recruitment, then an estimate of $B_{0.40}$ is calculated as the product of $SPR_{0.40}$ * equilibrium recruits, and this quantity is 124,289 t. The year 2003 spawning stock biomass is estimated as 224,526 t. Since reliable estimates of the 2003 spawning biomass (B), $B_{0.40}$, $F_{0.40}$, and $F_{0.35}$ exist and $B > B_{0.40}$ (224,526 t > 124,289 t), flathead sole reference fishing mortality is defined in tier 3a. For this tier, F_{ABC} is constrained to be $\leq F_{0.40}$, and F_{OFL} is defined to be $F_{0.35}$. The values of these quantities are:

2003 SSB estimate (B)	=	224,526 t
$B_{0.40}$	=	124,289 t
$F_{0.40}$	=	0.286
F_{ABC}	$\leq$	0.286
$F_{0.35}$	=	0.355
F_{OFL}	=	0.355

Specification of OFL and Maximum Permissible ABC

The estimated catch level for year 2003 associated with the overfishing level of $F = 0.355$ is 80,563 t. Because the flathead sole stock has not been overfished in recent years and the stock biomass is relatively high, it is not recommended to adjust F_{ABC}

downward from it upper bound; thus, the year 2003 recommended ABC associated with F_{ABC} of 0.286 is 66,410 t.

Standard Harvest and Recruitment Scenarios and Projection Methodology

A standard set of projections is required for each stock managed under Tiers 1, 2, or 3 of Amendment 56. This set of projections encompasses seven harvest scenarios designed to satisfy the requirements of Amendment 56, the National Environmental Policy Act, and the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA).

For each scenario, the projections begin with the vector of 2002 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2003 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2001. In each subsequent year, the fishing mortality rate is prescribed on the basis of the spawning biomass in that year and the respective harvest scenario. In each year, recruitment is drawn from an inverse Gaussian distribution whose parameters consist of maximum likelihood estimates determined from recruitments estimated in the assessment. Spawning biomass is computed in each year based on the time of peak spawning and the maturity and weight schedules described in the assessment. Total catch is assumed to equal the catch associated with the respective harvest scenario in all years. This projection scheme is run 1000 times to obtain distributions of possible future stock sizes, fishing mortality rates, and catches.

Five of the seven standard scenarios will be used in an Environmental Assessment prepared in conjunction with the final SAFE. These five scenarios, which are designed to provide a range of harvest alternatives that are likely to bracket the final TAC for 2003, are as follow ("*max* F_{ABC}" refers to the maximum permissible value of F_{ABC} under Amendment 56):

Scenario 1: In all future years, F is set equal to *max* F_{ABC}. (Rationale: Historically, TAC has been constrained by ABC, so this scenario provides a likely upper limit on future TACs.)

Scenario 2: In all future years, F is set equal to a constant fraction of *max* F_{ABC}, where this fraction is equal to the ratio of the F_{ABC} value for 2003 recommended in the assessment to the *max* F_{ABC} for 2003. (Rationale: When F_{ABC} is set at a value below *max* F_{ABC}, it is often set at the value recommended in the stock assessment.)

Scenario 3: In all future years, F is set equal to 50% of max F_{ABC}. (Rationale: This scenario provides a likely lower bound on F_{ABC} that still allows future harvest rates to be adjusted downward when stocks fall below reference levels.)

Scenario 4: In all future years, F is set equal to the 1997-2001 average F. (Rationale: For some stocks, TAC can be well below ABC, and recent average F may provide a better indicator of F_{TAC} than F_{ABC}.)

Scenario 5: In all future years, F is set equal to zero. (Rationale: In extreme cases, TAC may be set at a level close to zero.)

The recommended F_{ABC} and the maximum F_{ABC} are equivalent in this assessment, and five-year projections of the mean harvest and spawning stock biomass for the remaining four scenarios are shown in Tables 11.

Two other scenarios are needed to satisfy the MSFCMA's requirement to determine whether the flathead sole stock is currently in an overfished condition or is approaching an overfished condition. These two scenarios are as follows (for Tier 3 stocks, the MSY level is defined as $B_{35\%}$):

Scenario 6: In all future years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is overfished. If the stock is expected to be above its MSY level in 2003, then the stock is not overfished.)

Scenario 7: In 2003 and 2004, F is set equal to *max* F_{ABC}, and in all subsequent years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is approaching an overfished condition. If the stock is expected to be above its MSY level in 2005 under this scenario, then the stock is not approaching an overfished condition.)

Projections and Status Determination

The results of these two scenarios indicate that the flathead sole are neither overfished or approaching an overfished condition. With regard to assessing the current stock level, the expected stock size in the year 2003 of scenario 6 is 2.05 times its $B_{35\%}$ value of 108,753 t. With regard to whether the stock is likely to be in an overfished condition in the near future, the expected stock size in the year 2004 of scenario 7 is 1.30 times its $B_{35\%}$ value.

OTHER CONSIDERATIONS

Trophic studies indicate that flathead sole feed mainly on ophiuroids, tanner crab, osmerids, bivalves and polychaetes. Groundfish predators include Pacific cod, Pacific halibut, arrowtooth flounder and also cannibalism by large flathead sole, mostly on fish less than 20 cm standard length. Flatfish survival during the early life history period appears to be influenced by decadal-scale climatic variability. In particular, strong recruitment of winter-spawning flatfish (rock sole, flathead sole, and arrowtooth flounder) in the EBS occurred in the 1980s when wind-driven advection to inshore nursery areas occurred. During the 1990s, a shift in the wind pattern coincided with below average recruitments (Wilderbuer et al., in press).

Summary

In summary, several quantities pertinent to the management of the flathead sole are listed below.

Quantity	Value
M	0.20
Year 2003 Spawning stock biomass	224,526 t
F_{OFL}	0.355
Maximum F_{ABC}	0.286
Recommended F_{ABC}	0.286
OFL	80,563 t
Recommended ABC	66,410 t

References

Hare, S.R and N.J. Mantua. Empirical evidence for North Pacific regime shifts in 1977 and 1989. Progress in Oceanography 47:103-145.

Hart, J. L. 1973. Pacific fishes of Canada. Canadian Government Publishing Centre, Supply and Services Canada, Ottawa, Canada KIA OS9.

Hilborn, R. and M. Mangel. 1997. The ecological detective: confronting models with data. Princeton University Press, Princeton, NJ. 315 pp.

Overland, J.E, J.M. Adams, and N.A. Bond. 1999. Decadal variability of the Aleutian low and its relation to high-latitude circulation. Journal of Climate 12: 1542-1548.

Spencer, P.D., Walters, G. E., and T. K. Wilderbuer. 1999. Flathead sole. In Stock Assessment and Fishery Evaluation Document for Groundfish Resources in the Bering Sea/Aleutian Islands Region as Projected for 1999, p.391-430. North Pacific Fishery Management Council, P.O. Box 103136, Anchorage Alaska 99510

Spencer, P.D., Walters, G. E., and T. K. Wilderbuer. 2001. Flathead sole. In Stock Assessment and Fishery Evaluation Document for Groundfish Resources in the Bering Sea/Aleutian Islands Region as Projected for 1999, pp 7.1 – 7.37. North Pacific Fishery Management Council, P.O. Box 103136, Anchorage Alaska 99510

Walters, G. E., and T. K. Wilderbuer. 1997. Flathead sole. In Stock Assessment and Fishery Evaluation Document for Groundfish Resources in the Bering Sea/Aleutian Islands Region as Projected for 1998, p.271-295. North Pacific Fishery Management Council, P.O. Box 103136, Anchorage Alaska 99510.

Walters, G. E., and T. K. Wilderbuer. 1998. Flathead sole. In Stock Assessment and Fishery Evaluation Document for Groundfish Resources in the Bering Sea/Aleutian Islands Region as Projected for 1999, p.311-337. North Pacific Fishery Management Council, P.O. Box 103136, Anchorage Alaska 99510.

Wilderbuer, T, A. Hollowed, J. Ingraham, P.Spencer, L. Conner, N. Bond, and G. Walters. In press. Flatfish recruitment response to decadal climatic variability and ocean conditions in the eastern Bering Sea. Progress in Oceanography.

Table 1. Harvest (t) of flathead sole from 1977-2002

Year	Catch Biomass
1977	7909
1978	6957
1979	4351
1980	5247
1981	5218
1982	4509
1983	5240
1984	4458
1985	5636
1986	5208
1987	3595
1988	6783
1989	3604
1990	20245
1991	15602
1992	14239
1993	13664
1994	18455
1995	14707
1996	17344
1997	20704
1998	24397
1999	17842
2000	19983
2001	17586
2002	13873*

*NMFS Regional Office Report through September 21, 2002

Table 2. Research catches (t) of flathead sole in the BSAI area from 1979 to 2001.

Year	Research Catch (t)
1979	11.85
1980	6.19
1981	11.23
1982	20.36
1983	13.86
1984	13.51
1985	44.83
1986	13.79
1987	12.97
1988	29.86
1989	24.60
1990	26.76
1991	35.92
1992	18.92
1993	21.86
1994	30.23
1995	26.52
1996	20.87
1997	30.31
1998	23.02
1999	16.82
2000	19.09
2001	18.50
2002	25.16

Table 3. Restrictions on the flathead sole fishery from 1994 to 2001 in the Bering Sea – Aleutian Islands management area. Unless otherwise indicated, the closures were applied to the entire BSAI management area. Zone 1 consists of areas 508, 509, 512, and 516, whereas zone 2 consists of areas 513, 517, and 521.

Year	Dates	Bycatch Closure
1994	2/28 – 12/31	Red King crab cap (Zone 1 closed)
	5/7 – 12/31	Bairdi Tannner crab (Zone 2 closed)
	7/5 – 12/31	Annual halibut allowance
1995	2/21 – 3/30	First Seasonal halibut cap
	4/17 – 7/1	Second seasonal halibut cap
	8/1 – 12/31	Annual halibut allowance
1996	2/26 – 4/1	First Seasonal halibut cap
	4/13 – 7/1	Second seasonal halibut cap
	7/31 – 12/31	Annual halibut allowance
1997	2/20 – 4/1	First Seasonal halibut cap
	4/12 – 7/1	Second seasonal halibut cap
	7/25 – 12/31	Annual halibut allowance
1998	3/5 – 3/30	First Seasonal halibut cap
	4/21 – 7/1	Second seasonal halibut cap
	8/16 – 12/31	Annual halibut allowance
1999	2/26 – 3/30	First Seasonal halibut cap
	4/27 – 7/04	Second seasonal halibut cap
	8/31 – 12/31	Annual halibut allowance
2000	3/4 – 3/31	First Seasonal halibut cap
	4/30 – 7/03	Second seasonal halibut cap
	8/25 – 12/31	Annual halibut allowance
2001	3/20 – 3/31	First Seasonal halibut cap
	4/27 – 7/01	Second seasonal halibut cap
	8/24 – 12/31	Annual halibut allowance
2002	2/22 – 12/31	Red King crab cap (Zone 1 closed)
	3/1 – 3/31	First Seasonal halibut cap
	4/20 – 6/29	Second seasonal halibut cap
	7/29 – 12/31	Annual halibut allowance

Table 4. Total retained and discarded flathead sole, 1995-2002.

Year	Total Catch	Retained	Discarded	Percent Retained
1995	14707	7521	7186	51
1996	17344	8964	8380	52
1997	20704	10871	9833	53
1998	24397	17208	7189	70
1999	17892	13282	4610	74
2000	19983	14730	5253	74
2001	17586	14355	3231	82
2002*	13873	10227	3646	74

*NMFS regional office report through September 21, 2002

Table 5. Eastern Bering Sea flathead sole male catch at length group (millions)

	Length Group (cm)																						
Year	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	43	46	49	52	55	58
1977	0.00	0.00	0.00	0.04	0.12	0.31	0.86	0.84	0.80	1.64	3.08	4.04	3.63	2.04	0.71	0.13	0.03	0.05	0.04	0.00	0.00	0.00	0.00	0.00
1978	0.00	0.00	0.00	0.02	0.10	0.18	0.47	0.70	1.00	1.10	1.18	2.17	3.17	2.40	1.22	0.41	0.10	0.01	0.00	0.00	0.01	0.01	0.00	0.00
1979	0.00	0.00	0.00	0.02	0.13	0.22	0.32	0.62	0.70	0.44	0.45	0.66	1.18	1.67	1.15	0.51	0.17	0.05	0.01	0.00	0.00	0.00	0.00	0.00
1980	0.00	0.00	0.00	0.00	0.00	0.05	0.18	0.46	0.98	1.20	0.91	1.01	1.98	2.38	1.15	0.22	0.03	0.01	0.00	0.00	0.00	0.00	0.00	0.00
1981	0.00	0.00	0.00	0.02	0.08	0.35	0.43	0.11	0.18	0.35	1.03	2.29	2.59	1.81	0.83	0.19	0.03	0.05	0.03	0.00	0.00	0.00	0.00	0.00
1982	0.00	0.00	0.00	0.00	0.00	0.04	0.01	0.06	0.08	0.22	0.42	1.12	1.98	1.77	1.08	0.36	0.12	0.04	0.04	0.00	0.00	0.00	0.00	0.00
1983	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.09	0.14	0.44	1.02	1.52	1.57	1.15	0.49	0.14	0.04	0.02	0.01	0.01	0.01	0.01
1984	0.00	0.00	0.00	0.01	0.02	0.03	0.07	0.28	0.33	0.28	0.48	0.74	0.82	1.41	1.43	0.74	0.32	0.07	0.01	0.00	0.00	0.00	0.00	0.00
1985	0.00	0.00	0.00	0.00	0.01	0.04	0.05	0.22	0.34	0.44	0.57	0.66	0.88	1.01	1.21	1.16	0.59	0.25	0.04	0.02	0.03	0.03	0.04	0.02
1986	0.00	0.00	0.00	0.00	0.03	0.06	0.22	0.31	0.59	1.28	1.62	1.21	1.37	1.15	1.24	0.50	0.40	0.06	0.00	0.00	0.00	0.00	0.00	0.00
1987	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.04	0.10	0.16	0.31	0.50	1.15	1.47	0.84	0.22	0.02	0.00	0.00	0.00	0.00	0.00	0.00
1988	0.00	0.00	0.00	0.00	0.01	0.04	0.13	0.19	0.29	0.63	0.97	1.51	2.45	2.74	1.77	0.63	0.15	0.06	0.01	0.00	0.00	0.00	0.00	0.00
1989	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.13	0.22	0.23	0.45	0.68	0.89	1.04	1.00	0.58	0.22	0.11	0.02	0.00	0.00	0.00	0.00	0.00
1990	0.00	0.00	0.00	0.00	0.01	0.03	0.00	0.12	0.18	0.27	0.39	0.72	1.28	2.34	3.80	4.65	3.43	2.00	0.73	0.48	0.14	0.03	0.00	0.00
1991	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.06	0.12	0.23	0.39	0.97	1.39	2.06	3.18	4.14	2.89	1.28	0.27	0.09	0.07	0.02	0.00	0.00
1992	0.00	0.00	0.00	0.00	0.00	0.11	0.04	0.46	0.56	0.70	1.05	1.26	1.96	2.77	3.01	3.08	2.00	1.51	0.04	0.00	0.00	0.00	0.00	0.00
1993	0.00	0.00	0.00	0.00	0.01	0.02	0.02	0.01	0.08	0.18	0.53	1.12	1.29	2.21	3.40	3.46	1.98	1.02	0.37	0.06	0.00	0.00	0.00	0.00
1994	0.00	0.00	0.00	0.00	0.00	0.01	0.04	0.08	0.15	0.43	0.86	1.62	2.69	3.28	3.68	3.25	1.85	1.20	0.50	0.41	0.32	0.20	0.04	0.01
1995	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.08	0.14	0.28	0.68	1.32	2.27	3.31	3.55	2.37	1.15	0.43	0.24	0.04	0.00	0.00	0.00
1996	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.04	0.09	0.26	0.53	1.48	2.98	4.39	4.29	2.68	1.38	0.32	0.14	0.07	0.04	0.01	0.01
1997	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.08	0.15	0.41	1.17	1.99	3.15	4.66	5.18	4.75	2.90	1.35	0.13	0.00	0.00	0.00	0.00	0.00
1998	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.04	0.10	0.21	0.49	1.00	2.15	4.02	5.93	6.00	4.40	2.28	0.39	0.09	0.01	0.00	0.00	0.00
1999	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.08	0.22	0.49	1.16	2.08	3.02	4.09	3.95	2.86	1.70	0.34	0.11	0.02	0.01	0.01	0.00
2000	0.00	0.01	0.00	0.00	0.00	0.01	0.03	0.03	0.07	0.18	0.57	1.19	2.55	3.92	4.65	4.01	2.72	1.65	0.52	0.22	0.10	0.04	0.01	0.01
2001	0.00	0.00	0.00	0.00	0.01	0.01	0.02	0.06	0.07	0.19	0.32	0.92	1.60	2.79	3.75	3.83	2.87	1.86	0.36	0.15	0.07	0.04	0.03	0.02

Table 6. Eastern Bering Sea flathead sole female catch at length group (millions)

	Length Group (cm)																										
Year	**6**	**8**	**10**	**12**	**14**	**16**	**18**	**20**	**22**	**24**	**26**	**28**	**30**	**32**	**34**	**36**	**38**	**40**	**43**	**46**	**49**	**52**	**55**	**58**
1977	0.00	0.00	0.00	0.04	0.11	0.26	0.67	0.82	0.66	0.76	1.18	1.38	1.77	1.80	1.52	1.21	0.81	0.42	0.06	0.02	0.01	0.00	0.00	0.01
1978	0.00	0.00	0.00	0.01	0.03	0.09	0.22	0.45	0.53	0.57	0.53	0.60	0.88	1.26	1.43	1.19	0.83	0.73	0.20	0.04	0.01	0.00	0.00	0.00
1979	0.00	0.00	0.00	0.01	0.04	0.08	0.18	0.36	0.43	0.32	0.28	0.30	0.30	0.31	0.46	0.60	0.62	0.68	0.32	0.11	0.01	0.00	0.00	0.00
1980	0.00	0.00	0.00	0.00	0.01	0.06	0.22	0.48	0.85	1.23	0.98	0.91	0.80	0.67	0.60	0.66	0.65	0.55	0.15	0.02	0.01	0.00	0.00	0.00
1981	0.00	0.00	0.00	0.01	0.01	0.12	0.21	0.09	0.05	0.09	0.29	0.67	0.99	1.12	0.86	0.61	0.54	0.59	0.28	0.07	0.01	0.00	0.00	0.00
1982	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.04	0.13	0.35	0.71	1.15	1.02	0.72	0.37	0.39	0.52	0.24	0.06	0.00	0.00	0.00	0.00
1983	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.02	0.00	0.02	0.05	0.12	0.23	0.34	0.58	1.02	0.71	0.30	0.11	0.03	0.03	0.00
1984	0.00	0.00	0.00	0.01	0.02	0.03	0.06	0.16	0.17	0.12	0.16	0.25	0.28	0.36	0.68	0.89	0.72	0.61	0.25	0.08	0.01	0.00	0.00	0.00
1985	0.00	0.00	0.00	0.01	0.01	0.03	0.03	0.09	0.16	0.16	0.19	0.22	0.26	0.38	0.51	0.72	0.81	1.06	0.41	0.12	0.06	0.02	0.03	0.01
1986	0.00	0.00	0.00	0.00	0.02	0.11	0.39	0.35	0.50	0.35	0.45	0.65	0.69	0.60	0.63	0.80	0.88	0.56	0.24	0.06	0.00	0.00	0.00	0.00
1987	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.01	0.04	0.09	0.15	0.22	0.35	0.83	0.87	0.61	0.47	0.09	0.02	0.00	0.00	0.00	0.00
1988	0.00	0.00	0.00	0.00	0.01	0.02	0.07	0.09	0.13	0.26	0.27	0.52	0.86	1.18	1.27	1.12	0.90	0.77	0.30	0.10	0.02	0.00	0.00	0.00
1989	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.05	0.10	0.10	0.11	0.21	0.29	0.40	0.46	0.55	0.52	0.45	0.25	0.12	0.04	0.00	0.00	0.00
1990	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.04	0.06	0.08	0.19	0.23	0.47	0.65	1.28	1.93	2.64	3.58	2.59	1.23	0.25	0.03	0.01	0.00
1991	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.03	0.08	0.18	0.36	0.52	0.79	1.07	1.31	2.02	2.75	1.94	0.72	0.27	0.05	0.02	0.00
1992	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.06	0.21	0.27	0.89	1.31	1.63	1.90	2.52	1.57	0.59	0.27	0.00	0.00	0.00
1993	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.10	0.14	0.22	0.46	0.68	0.87	1.21	1.39	2.63	2.10	0.57	0.14	0.02	0.00	0.00
1994	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.04	0.08	0.14	0.32	0.53	0.73	1.53	2.10	3.21	2.27	1.09	0.56	0.13	0.02	0.02
1995	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.04	0.04	0.07	0.16	0.25	0.48	0.66	1.00	1.17	2.26	2.41	1.22	0.29	0.04	0.00	0.00
1996	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.03	0.05	0.08	0.18	0.43	0.93	1.37	1.58	2.53	2.81	1.42	0.31	0.06	0.01	0.00
1997	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.04	0.10	0.15	0.31	0.53	0.77	1.18	1.72	2.18	2.97	2.81	1.68	0.45	0.06	0.00	0.00
1998	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.05	0.09	0.21	0.43	0.78	1.24	1.84	2.21	3.42	3.20	2.26	0.82	0.11	0.01	0.00
1999	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.03	0.10	0.19	0.45	0.73	1.12	1.41	1.75	2.83	2.32	1.30	0.43	0.06	0.02	0.01
2000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.05	0.13	0.27	0.65	1.07	1.61	1.93	1.83	2.84	2.27	1.53	0.54	0.09	0.01	0.01
2001	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.02	0.04	0.09	0.26	0.30	0.65	1.02	1.53	1.66	2.60	2.33	1.32	0.48	0.09	0.02	0.01

Table 7. Estimated biomass of flathead sole from the EBS and Aleutian Islands Trawl survey.

Year	Area	Biomass Estimate	Standard Deviation
1975	EBS	100,700	
1979	EBS	104,900	
1980	EBS	117,500	
	Aleut.	3,300	
1981	EBS	162,900	
1982	EBS	191,988	17,031
1983	EBS	269,419	27,035
	Aleut.	1,500	
1984	EBS	341,697	28,774
1985	EBS	276,350	20,088
1986	EBS	357,951	31,402
	Aleut.	9,000	
1987	EBS	394,758	37,011
1988	EBS	572,805	49,696
1989	EBS	536,433	45.039
1990	EBS	628,235	54,945
1991	EBS	544,893	42,102
	Aleut.	6,885	1,368
1992	EBS	651,384	66,213
1993	EBS	610,259	43,451
1994	EBS	726,212	51,190
	Aleut.	9,917	2,241
1995	EBS	593,412	51,934
1996	EBS	616,373	55,752
1997	EBS	807,825	174,348
	Aleut.	11,540	2,725
1998	EBS	692,234	143,412
1999	EBS	394,822	34,325
2000	EBS	399,298	34,692
2000	Aleut	8,795	1,996
2001	EBS	514,023	53,489
2002	EBS	574,946	102,680
2002	Aleut	9,894	2,410

Table 8. Eastern Bering Sea flathead sole male numbers at length group (millions) estimated from the NMFS trawl surveys

Year	Length Group (cm)																						
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	43	46	49	52	55	58
1982	0.27	0.30	1.42	19.37	30.56	27.81	33.61	46.44	54.95	63.58	84.48	90.19	72.52	31.55	10.41	3.08	0.59	0.42	0.00	0.00	0.00	0.00	0.00	0.00
1983	0.47	1.36	16.88	47.98	28.14	49.06	65.83	56.16	49.88	57.29	71.20	85.44	82.41	58.81	23.63	6.70	1.37	0.12	0.00	0.00	0.00	0.00	0.00	0.00
1984	0.72	1.50	10.41	31.20	57.55	94.49	72.63	68.82	79.83	79.91	87.22	96.03	92.24	70.87	34.05	7.58	3.57	0.12	0.00	0.14	0.00	0.00	0.00	0.00
1985	0.03	2.70	4.28	8.83	23.65	39.88	61.01	86.03	75.21	57.16	70.29	74.92	80.93	60.96	38.86	14.30	3.33	0.78	0.00	0.00	0.00	0.00	0.00	0.00
1986	0.47	0.83	7.25	23.71	17.42	22.83	38.52	65.07	74.08	82.94	84.31	69.95	87.56	88.82	49.43	20.70	6.90	1.66	0.11	0.00	0.00	0.00	0.00	0.00
1987	0.06	0.21	7.51	24.00	27.07	44.09	43.98	53.56	63.01	79.70	78.04	90.86	99.30	97.64	55.07	28.65	14.99	3.82	0.00	0.00	0.00	0.00	0.00	0.00
1988	0.54	1.63	5.23	30.89	77.10	101.89	73.97	76.37	64.69	70.87	75.18	86.13	115.63	137.93	120.56	51.74	17.67	5.16	0.26	0.00	0.00	0.00	0.00	0.00
1989	0.00	1.54	17.37	70.04	40.33	43.44	127.71	102.70	102.99	72.95	74.82	76.26	76.47	128.41	127.72	58.91	18.03	3.02	0.00	0.00	0.00	0.00	0.00	0.00
1990	0.00	1.30	4.75	17.32	74.03	78.17	64.41	94.99	114.40	99.89	96.77	97.86	109.67	136.15	132.40	69.94	27.55	5.46	0.50	0.00	0.00	0.00	0.00	0.00
1991	0.10	0.70	12.03	8.80	10.32	47.57	91.91	125.85	119.07	112.65	111.83	92.10	101.78	95.91	107.64	72.53	21.39	4.77	0.45	0.06	0.00	0.00	0.00	0.00
1992	0.00	0.02	3.46	44.85	74.84	45.93	49.48	91.69	128.81	160.50	144.34	119.00	124.41	135.70	138.54	88.97	32.19	6.55	0.32	0.02	0.18	0.00	0.00	0.00
1993	0.00	0.91	6.95	13.50	19.31	58.28	64.41	61.04	72.45	109.60	139.13	138.74	121.89	128.75	117.83	68.84	26.74	7.10	0.24	0.00	0.00	0.00	0.00	0.00
1994	0.00	0.89	4.97	20.10	43.45	65.78	87.74	75.73	68.50	92.89	126.88	142.66	157.12	153.69	144.32	95.41	31.71	8.37	0.39	0.00	0.00	0.00	0.00	0.00
1995	0.00	0.12	1.97	7.68	19.00	34.32	43.99	60.15	70.08	65.63	106.64	133.01	152.53	138.54	119.62	72.88	31.93	10.52	0.50	0.14	0.00	0.00	0.00	0.00
1996	0.07	0.63	3.15	19.70	38.02	35.65	55.73	69.11	74.66	77.90	89.21	116.17	139.29	145.85	135.79	85.00	33.76	12.38	1.01	0.00	0.00	0.03	0.00	0.00
1997	0.06	0.48	3.01	10.40	12.46	24.23	30.26	40.34	53.39	66.34	73.81	91.47	143.20	152.03	145.64	102.15	53.45	23.84	2.37	1.85	0.00	0.00	0.00	0.00
1998	0.06	1.26	17.18	34.49	18.23	26.35	29.32	37.45	46.66	69.57	77.23	94.44	135.44	161.08	157.74	106.86	59.75	14.97	2.64	0.44	0.00	0.00	0.00	0.00
1999	0.00	0.46	2.61	7.34	20.22	16.06	17.74	29.29	31.18	48.08	59.45	65.48	79.45	98.03	82.37	45.35	21.04	10.86	1.04	0.10	0.00	0.00	0.00	0.00
2000	0.06	0.36	5.35	7.63	11.38	24.17	22.09	25.56	28.20	43.09	63.81	64.82	87.61	87.90	73.77	49.16	19.36	7.65	0.58	0.24	0.03	0.00	0.00	0.00
2001	0.00	0.74	5.02	6.55	16.95	20.75	37.24	63.50	59.97	46.26	59.54	97.84	120.11	122.74	105.09	59.81	30.72	9.79	1.89	0.56	0.02	0.02	0.00	0.00
2002	0.07	0.50	1.93	6.47	13.39	17.91	21.78	35.80	57.22	59.29	59.30	74.40	107.94	115.19	106.72	62.82	25.77	12.38	2.01	2.99	0.02	0.00	0.00	0.00

Table 9. Eastern Bering Sea flathead sole female numbers at length group (millions) estimated from the NMFS trawl surveys

Year	Length Group (cm) 6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	43	46	49	52	55	58
1982	0.00	0.00	1.23	16.77	24.10	19.75	29.37	46.82	48.32	48.18	53.37	66.87	70.42	55.20	32.85	13.48	6.75	8.71	1.67	0.40	0.00	0.00	0.00	0.00
1983	0.00	0.48	11.91	36.92	24.91	43.47	55.95	53.01	45.10	50.33	55.24	61.04	76.61	78.66	70.04	32.20	15.53	9.07	1.57	0.47	0.00	0.00	0.00	0.00
1984	0.00	0.61	6.07	33.44	58.49	80.38	62.89	56.56	71.80	71.37	72.40	83.43	83.20	84.64	84.32	56.00	26.95	12.30	1.26	0.92	0.03	0.00	0.00	0.00
1985	0.00	1.18	1.24	7.94	21.60	33.11	52.72	78.33	67.73	50.09	49.00	53.25	54.64	56.40	52.35	34.41	23.56	14.47	4.18	1.01	0.00	0.00	0.00	0.00
1986	0.00	0.47	3.44	12.09	13.38	17.44	30.88	46.88	64.65	75.02	66.41	60.58	68.37	70.62	74.52	55.19	40.46	30.46	6.97	2.00	0.18	0.00	0.00	0.00
1987	0.00	0.00	4.26	18.41	26.98	39.89	40.57	48.68	45.24	56.28	66.52	70.32	71.67	70.27	78.82	60.34	46.75	35.05	13.75	2.76	0.10	0.00	0.00	0.00
1988	0.00	0.00	2.50	19.33	72.66	98.75	92.24	114.64	80.63	74.65	78.18	78.82	79.20	101.09	104.48	97.85	69.78	63.72	26.02	3.48	1.34	0.00	0.00	0.00
1989	0.00	0.14	15.55	43.40	28.12	39.99	104.40	103.79	109.92	77.05	62.33	67.97	78.15	68.05	85.35	91.01	67.13	65.48	26.59	7.98	0.81	0.00	0.00	0.00
1990	0.00	0.20	1.95	13.16	59.00	70.08	48.57	67.86	91.46	93.57	82.06	74.66	66.36	77.56	72.18	83.78	80.79	91.95	39.88	11.28	2.42	0.00	0.00	0.00
1991	0.00	0.84	5.00	4.75	6.97	31.83	69.33	95.63	94.66	104.16	99.36	89.17	68.35	77.35	86.47	76.83	107.87	124.83	44.33	14.63	0.96	0.00	0.00	0.00
1992	0.00	0.00	3.99	30.73	54.87	42.64	48.51	75.78	102.93	123.14	115.07	114.32	83.74	79.04	84.58	85.11	81.45	94.70	51.89	16.50	2.48	0.13	0.00	0.00
1993	0.04	0.53	4.80	9.93	19.37	50.29	59.06	46.11	70.87	95.05	97.50	109.18	106.75	85.77	73.98	67.04	58.95	95.20	49.32	15.80	2.88	0.09	0.00	0.00
1994	0.00	0.41	2.31	13.29	31.96	47.10	66.62	56.17	47.42	74.66	97.27	118.08	125.57	112.85	96.71	77.87	78.94	103.18	70.94	25.65	3.59	0.32	0.00	0.00
1995	0.00	0.00	1.18	5.24	15.94	30.57	38.90	54.44	50.61	49.62	62.06	80.36	97.65	92.04	80.90	67.28	59.77	69.60	50.84	16.61	5.56	0.25	0.00	0.00
1996	0.00	0.18	3.04	18.72	28.21	43.06	47.93	61.57	61.11	66.25	65.12	64.30	75.83	88.04	93.11	81.05	52.62	72.78	51.34	23.32	3.15	0.28	0.00	0.00
1997	0.00	0.49	1.61	6.57	14.30	21.96	29.35	36.26	41.09	47.46	59.36	63.51	80.61	94.61	112.36	109.09	98.04	129.84	108.43	33.09	7.92	0.61	0.00	0.00
1998	0.00	0.58	12.84	23.99	11.43	20.98	28.26	41.44	45.34	47.69	66.99	72.37	61.31	76.22	94.19	89.04	80.66	87.72	57.85	24.88	11.34	1.39	0.00	0.00
1999	0.00	0.14	2.12	5.82	14.45	15.77	14.68	19.89	28.42	34.79	40.97	40.77	43.54	49.23	64.20	59.79	45.34	42.79	27.76	15.04	7.70	0.95	0.17	0.00
2000	0.25	0.40	1.71	4.95	9.06	17.91	18.47	21.53	20.59	29.62	38.01	40.90	53.51	58.93	64.24	69.28	50.05	51.29	28.99	12.80	4.39	0.53	0.00	0.00
2001	0.16	0.41	3.25	5.06	8.55	15.44	29.09	46.11	48.49	39.58	39.80	59.62	66.61	78.40	88.21	82.83	59.78	62.02	38.83	18.80	4.30	0.86	0.07	0.00
2002	0.19	0.61	2.10	4.97	11.28	14.39	18.01	26.15	37.78	41.69	42.39	49.30	52.47	73.50	83.33	67.14	60.27	65.78	52.45	43.96	24.40	5.21	0.96	0.00

Table 10. Estimated total biomass (ages 3+), female spawner biomass, and recruitment (age 3), with comparison to the 2001 SAFE estimates

	Spawning stock biomass (t)		Total biomass (t)		Recruitment (thousands)	
	Assessment		Assessment		Assessment	
	2002	2001	2002	2001	2002	2001
1977	44492	65311	147395	227194		
1978	40863	61172	173919	249219	295332	179074
1979	38300	58209	210745	290029	629479	597397
1980	38716	58979	251075	340857	553136	706972
1981	46110	69519	301291	406862	1050990	1322300
1982	66188	95417	354046	458190	891554	941226
1983	92361	129963	415692	534569	1231040	1339020
1984	116682	158964	485219	611331	1371310	1370640
1985	139629	185201	544454	663933	573028	490698
1986	163314	214167	596547	715510	686559	769511
1987	190196	244811	646072	767380	985294	1110880
1988	221497	280053	697681	818046	1203230	1197110
1989	252176	312100	738525	854307	853650	885244
1990	279135	339399	781561	897161	1107550	1043330
1991	290204	348064	794387	897867	421618	362549
1992	301179	357550	801780	896629	514737	507167
1993	313456	369442	802677	890830	629332	623039
1994	325670	380168	798126	878997	662538	635981
1995	335530	388974	784457	855431	429441	322793
1996	336783	385633	763224	827276	452750	450196
1997	330643	374645	732040	786227	230540	206765
1998	318723	358020	694729	742433	366841	384467
1999	304023	339155	653873	698009	401273	438230
2000	291297	321697	616949	655716	322781	293801
2001	275420	301404	576586	612337	210182	264979
2002	258692		538042		232759	

Table 11. Projections of spawning biomass, catch, fishing mortality rate, and catch for each of the several scenarios. The values of $B_{40\%}$ and $B_{35\%}$ are 124,289 t and 108,753 t, respectively.

Sp. Biomass	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*
2002	248587	248587	248587	248587	248587	248587	248587
2003	224526	224526	228625	231080	232803	222585	224526
2004	177420	177420	199702	214306	225146	167711	177419
2005	142832	142832	175763	199288	217744	129602	141633
2006	117144	117144	155363	185196	209898	103360	111301
2007	100200	100200	138786	172607	202105	88856.5	93153.4
2008	93889.2	93889.2	129530	165818	199090	84346.2	86788.6
2009	94843.9	94843.9	126832	164045	199839	86636.3	87975
2010	100189	100189	129798	167404	205293	92725.8	93399.7
2011	106810	106810	135566	173700	213558	99532.7	99816.5
2012	112845	112845	142114	181111	222922	105290	105365
2013	117457	117457	148144	188167	231747	109328	109306
2014	120797	120797	153556	194943	240417	111957	111903
2015	123106	123106	158107	200916	248152	113566	113511
F	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*
2002	0.0518808	0.0518808	0.0518798	0.0518838	0.0518797	0.0518801	0.0518822
2003	0.286105	0.286105	0.143052	0.0586308	0	0.354868	0.286105
2004	0.286105	0.286105	0.143052	0.0586308	0	0.354868	0.286105
2005	0.286105	0.286105	0.143052	0.0586308	0	0.354868	0.354868
2006	0.268789	0.268789	0.143052	0.0586308	0	0.291965	0.315833
2007	0.227733	0.227733	0.143052	0.0586308	0	0.248375	0.26129
2008	0.212442	0.212442	0.142202	0.0586308	0	0.23482	0.24216
2009	0.214586	0.214586	0.138571	0.0586308	0	0.241663	0.245679
2010	0.226442	0.226442	0.138298	0.0586308	0	0.259356	0.261355
2011	0.240119	0.240119	0.139412	0.0586308	0	0.278381	0.279208
2012	0.251134	0.251134	0.140571	0.0586308	0	0.293752	0.293975
2013	0.258659	0.258659	0.14129	0.0586308	0	0.303695	0.303658
2014	0.2634	0.2634	0.141886	0.0586308	0	0.309907	0.30979
2015	0.2664	0.2664	0.142308	0.0586308	0	0.31355	0.31343
Catch	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7
2002	13873.6	13873.6	13873.3	13874.4	13873.3	13873.4	13874
2003	66409.5	66409.5	34802.3	14672.9	0	80563.4	66409.5
2004	53328.6	53328.6	30669.1	13674.6	0	61921.3	53328.6
2005	43458.3	43458.3	27170.1	12761.3	0	48578.3	52758.3
2006	34159.7	34159.7	24279.8	11951	0	32875.6	37949.4
2007	25354.1	25354.1	21943.1	11232.4	0	24619.4	27040
2008	22057.6	22057.6	20272	10743.3	0	21919.8	23242.6
2009	21799.3	21799.3	18908.9	10418.3	0	22344.2	23095.1
2010	23395.9	23395.9	18734.4	10362.6	0	24646.8	25062.5
2011	25701.3	25701.3	19225.8	10518.9	0	27582.9	27789.5
2012	27948.3	27948.3	19998.7	10810.4	0	30330.8	30413.8
2013	29803.6	29803.6	20811.7	11153.8	0	32428.8	32446.2
2014	31244.9	31244.9	21647.3	11540.4	0	33960.8	33950
2015	32302.7	32302.7	22396.4	11909.3	0	34986.5	34966.8

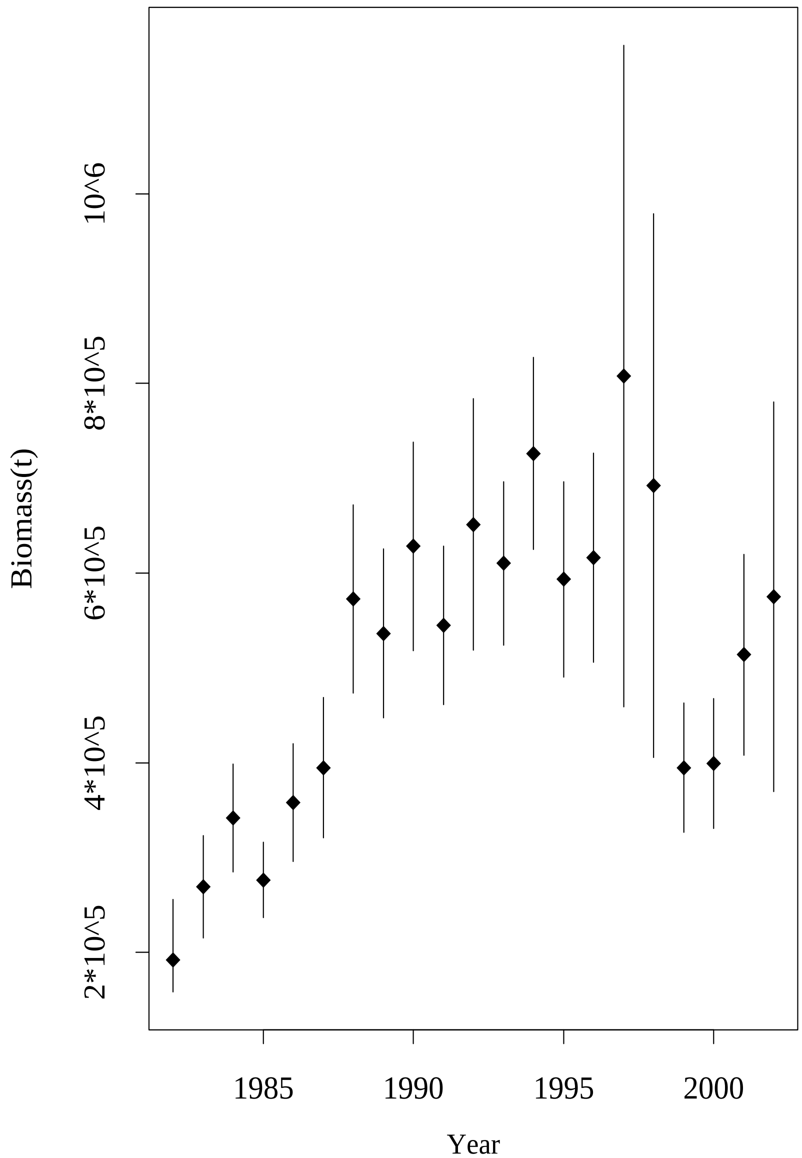


Figure 1. Estimated survey biomass and 95% CIs

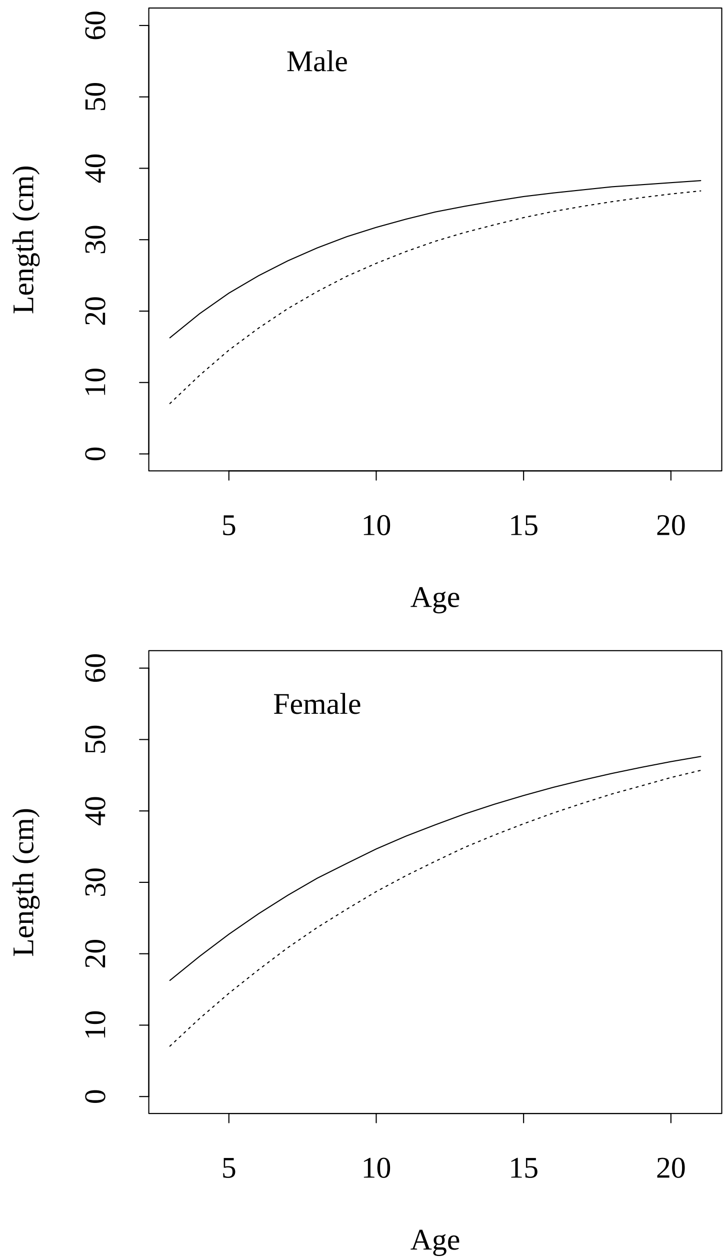


Figure 2. Estimated growth curves underlying the transition matrices. The solid line is the update from survey data and the dashed line is from previous assessments

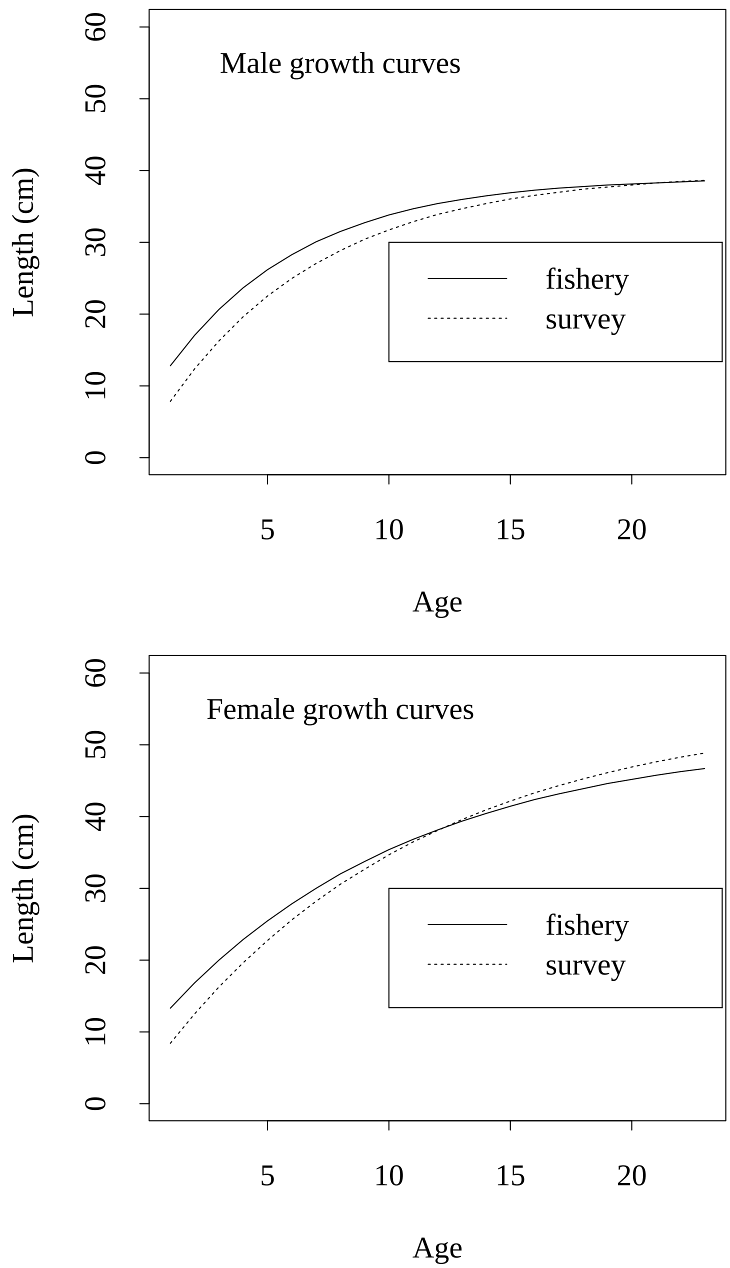


Figure 3. Estimated growth curves from fishery and survey data

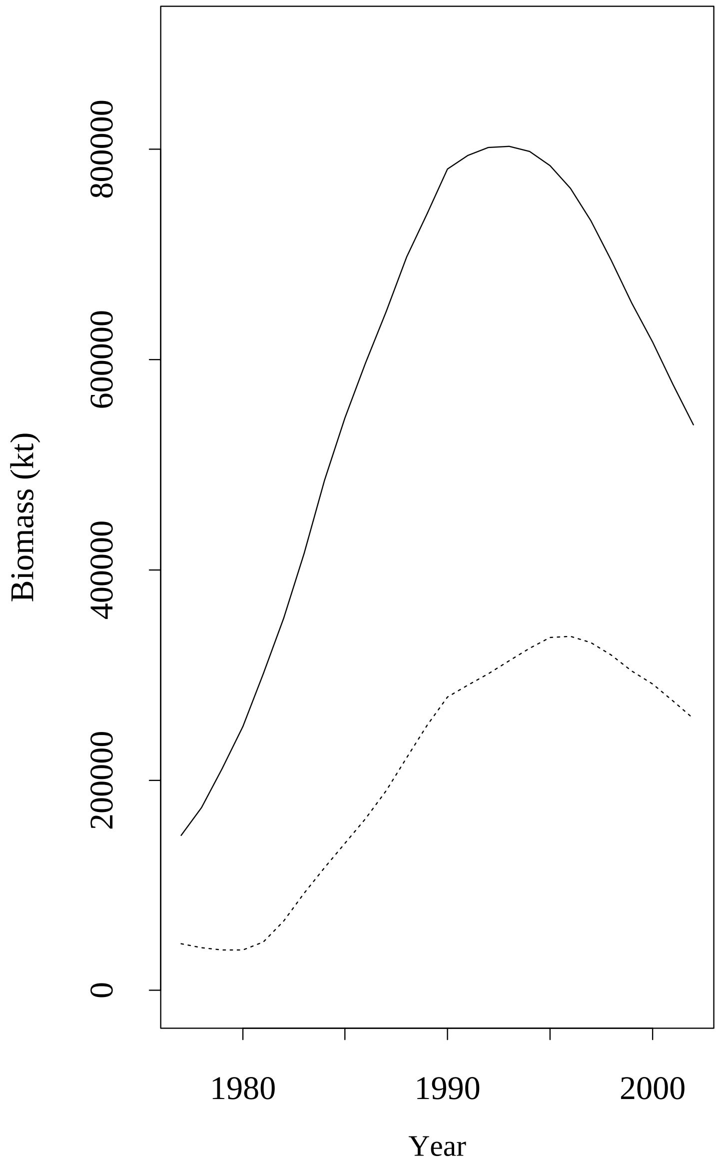


Figure 4. Estimated total (solid line) and spawner (dashed line) biomass

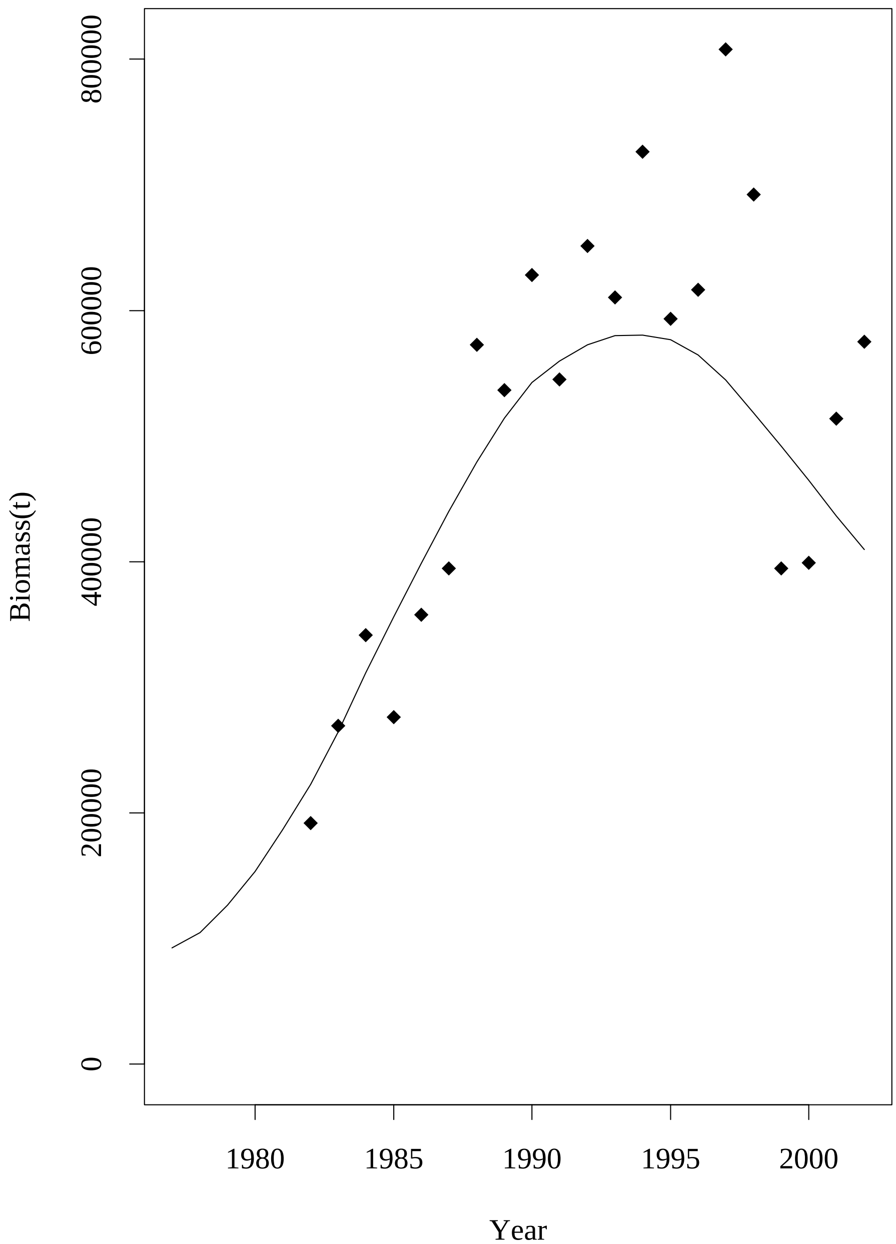


Figure 5. Estimated survey biomass of flathead sole
with observed survey biomass

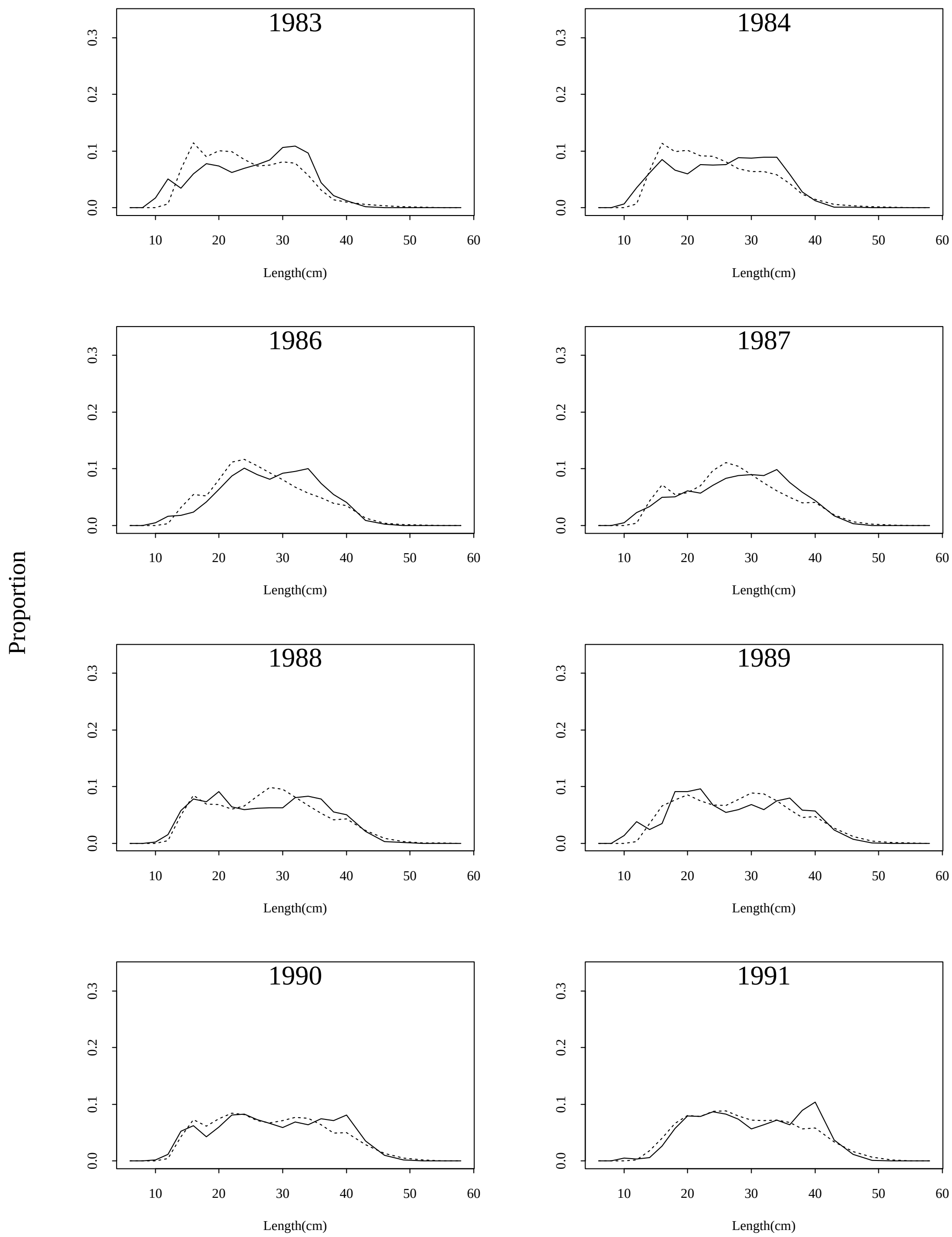


Figure 6. Female survey length composition by year (solid line = observed, dotted line = predicted)

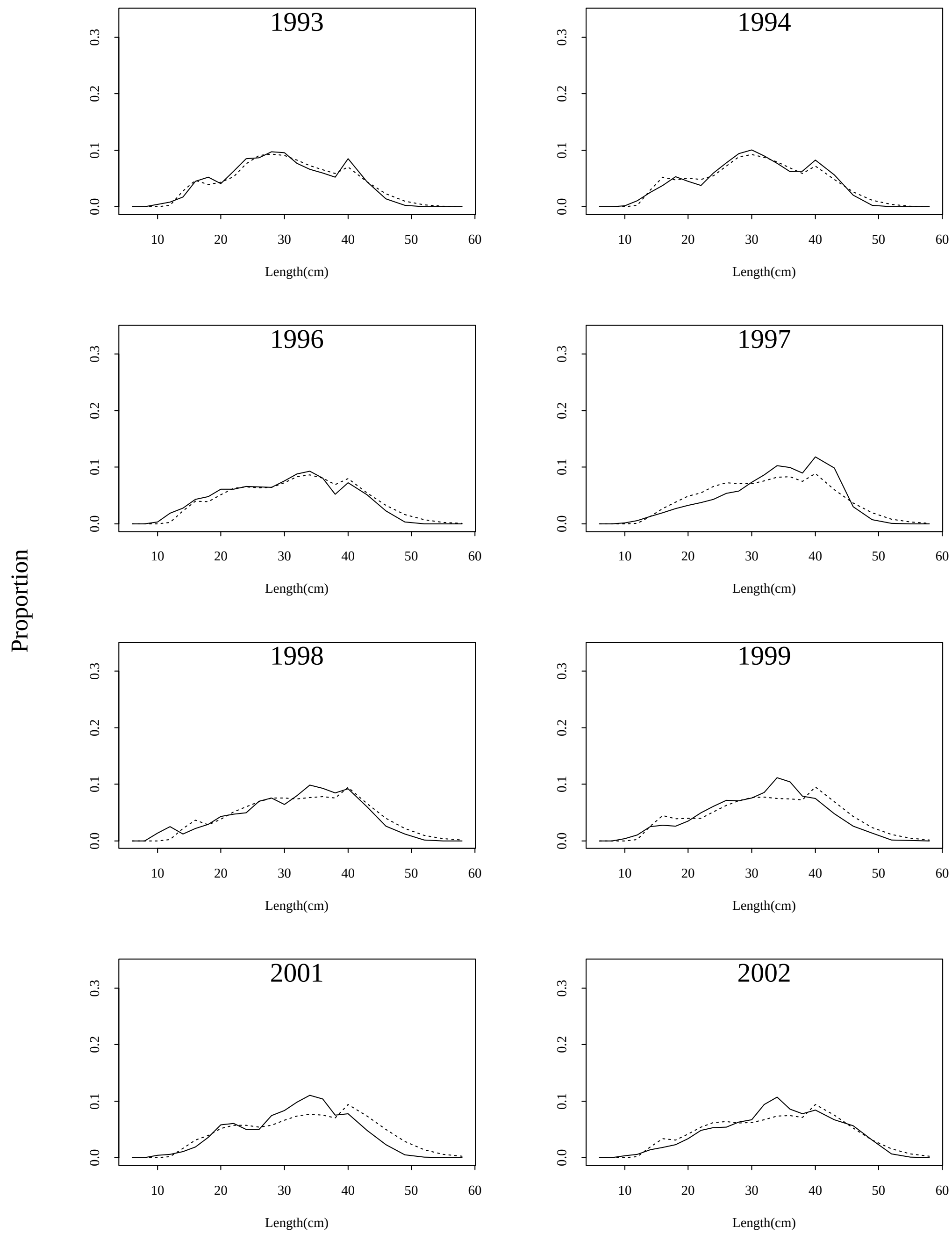


Figure 6. Female survey length composition by year (solid line = observed, dotted line = predicted)

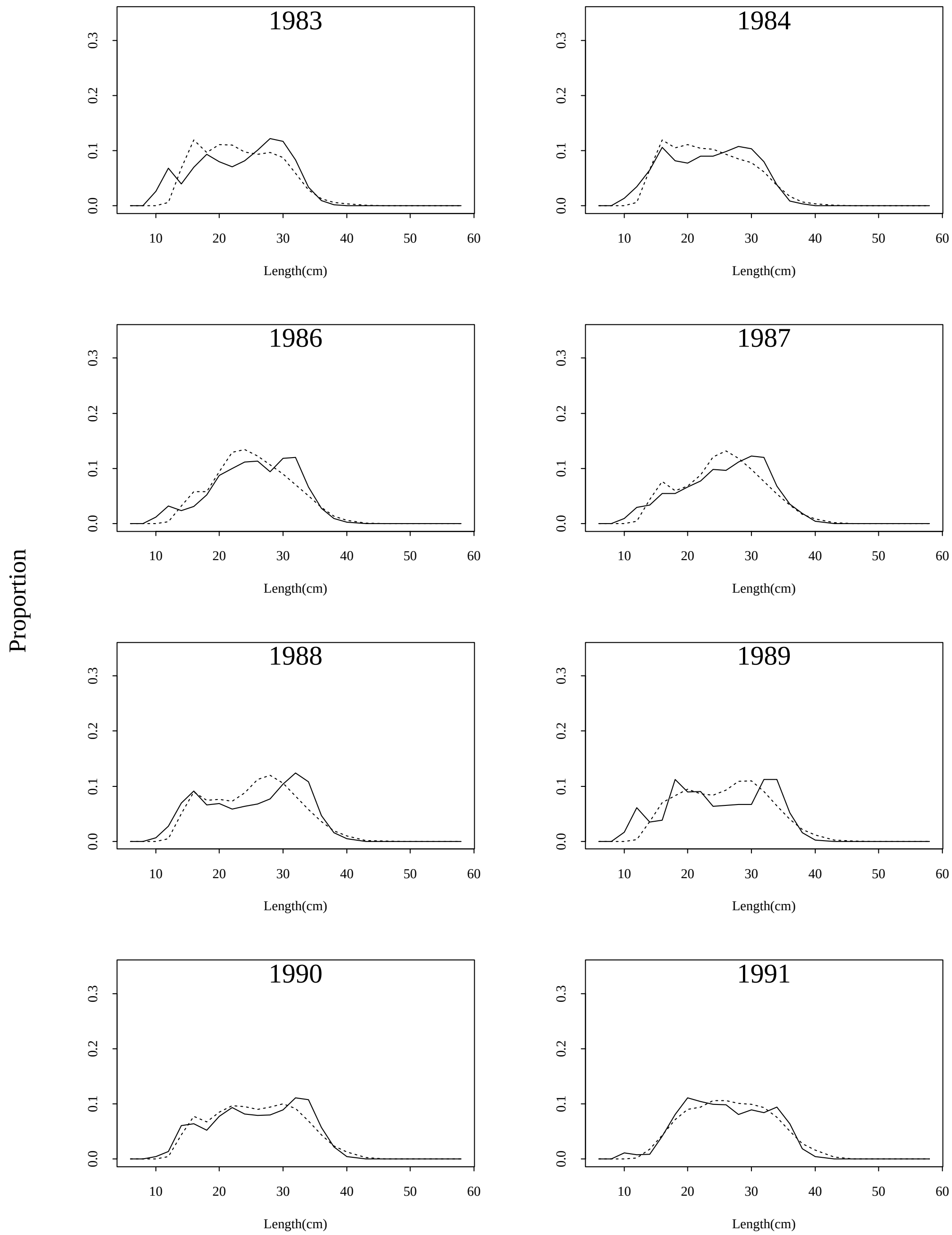


Figure 7. Male survey length composition by year (solid line = observed, dotted line = predicted)

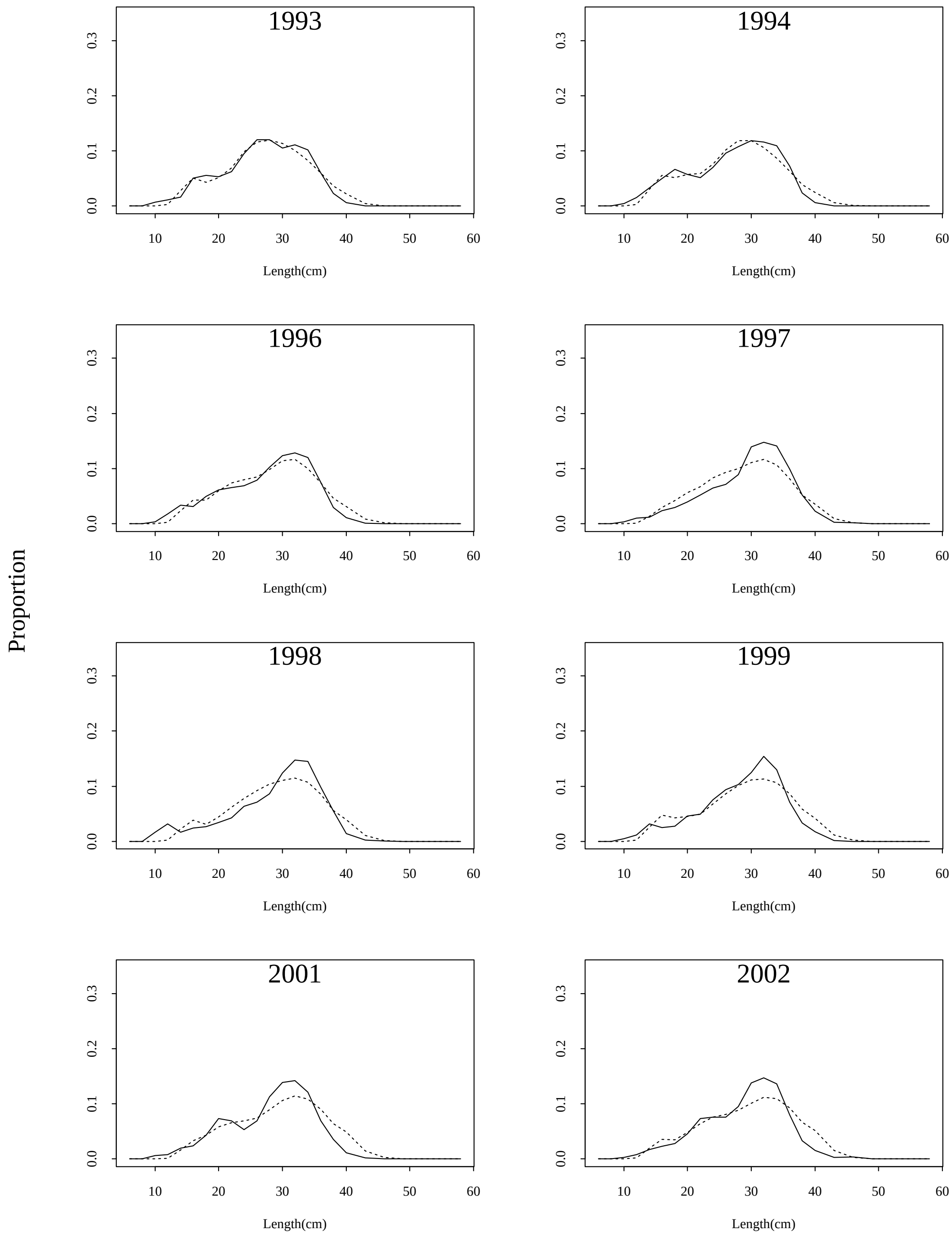


Figure 7. Male survey length composition by year (solid line = observed, dotted line = predicted)

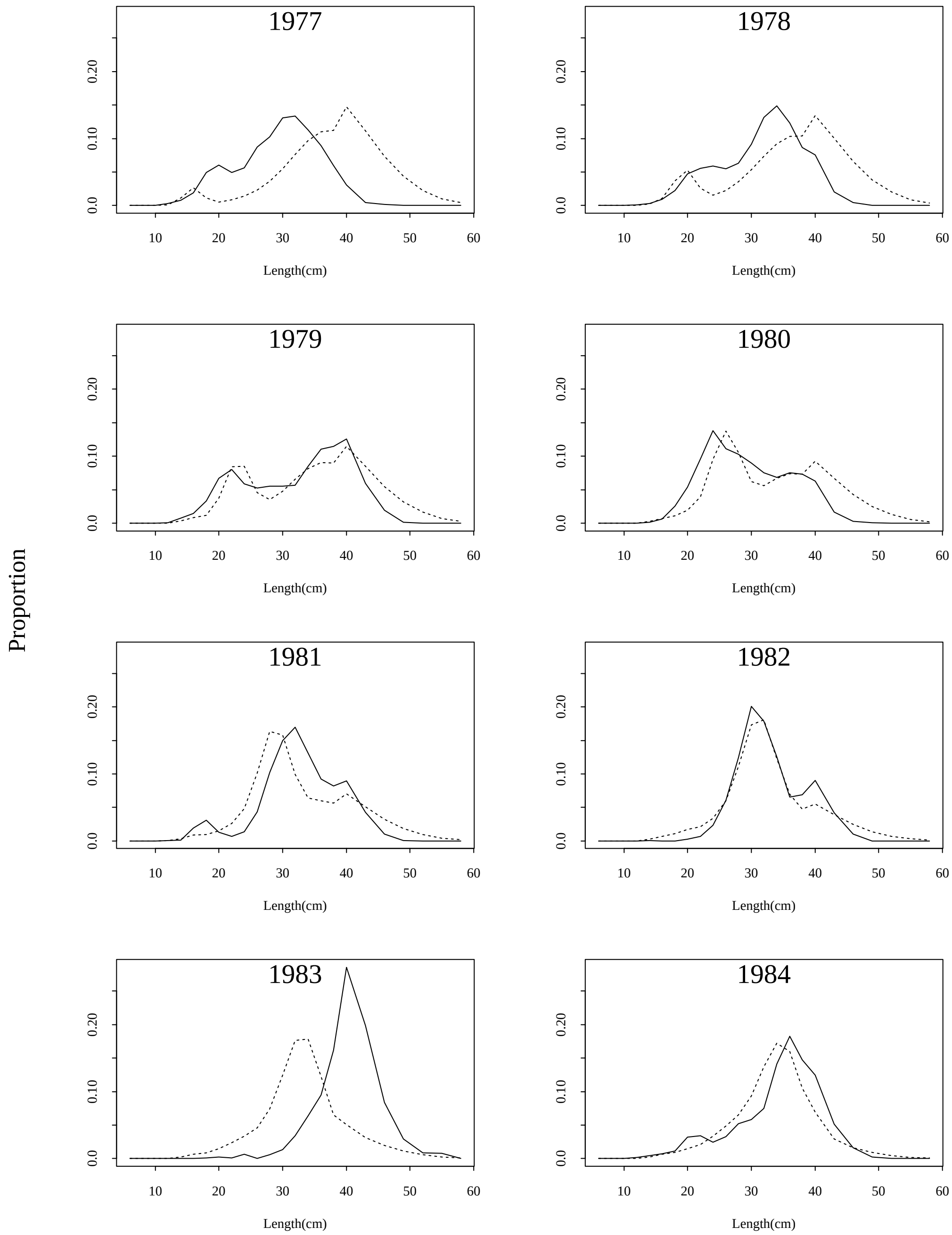


Figure 8. Female fishery length composition by year (solid line = observed, dotted line = predicted)

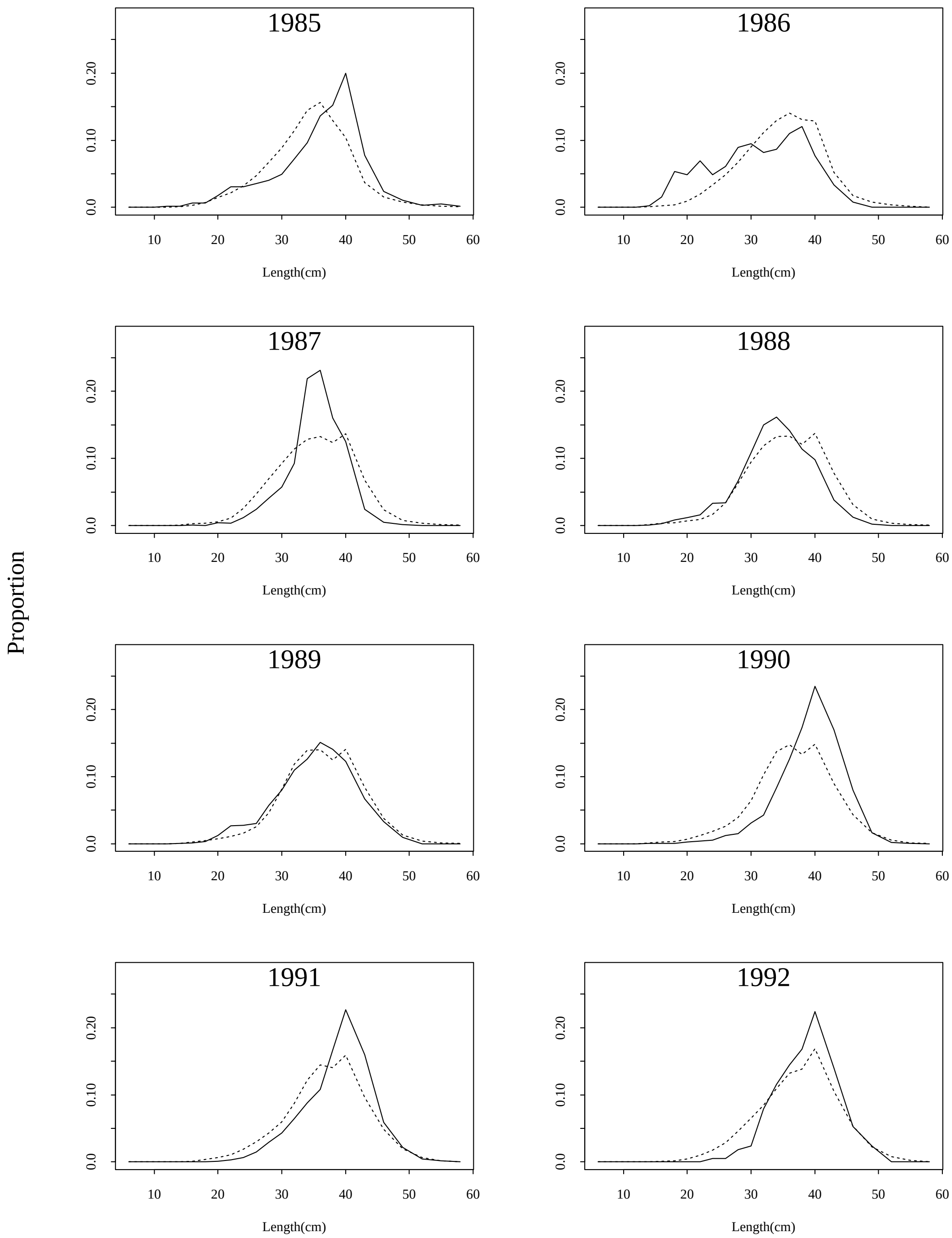


Figure 8. Female fishery length composition by year (solid line = observed, dotted line = predicted)

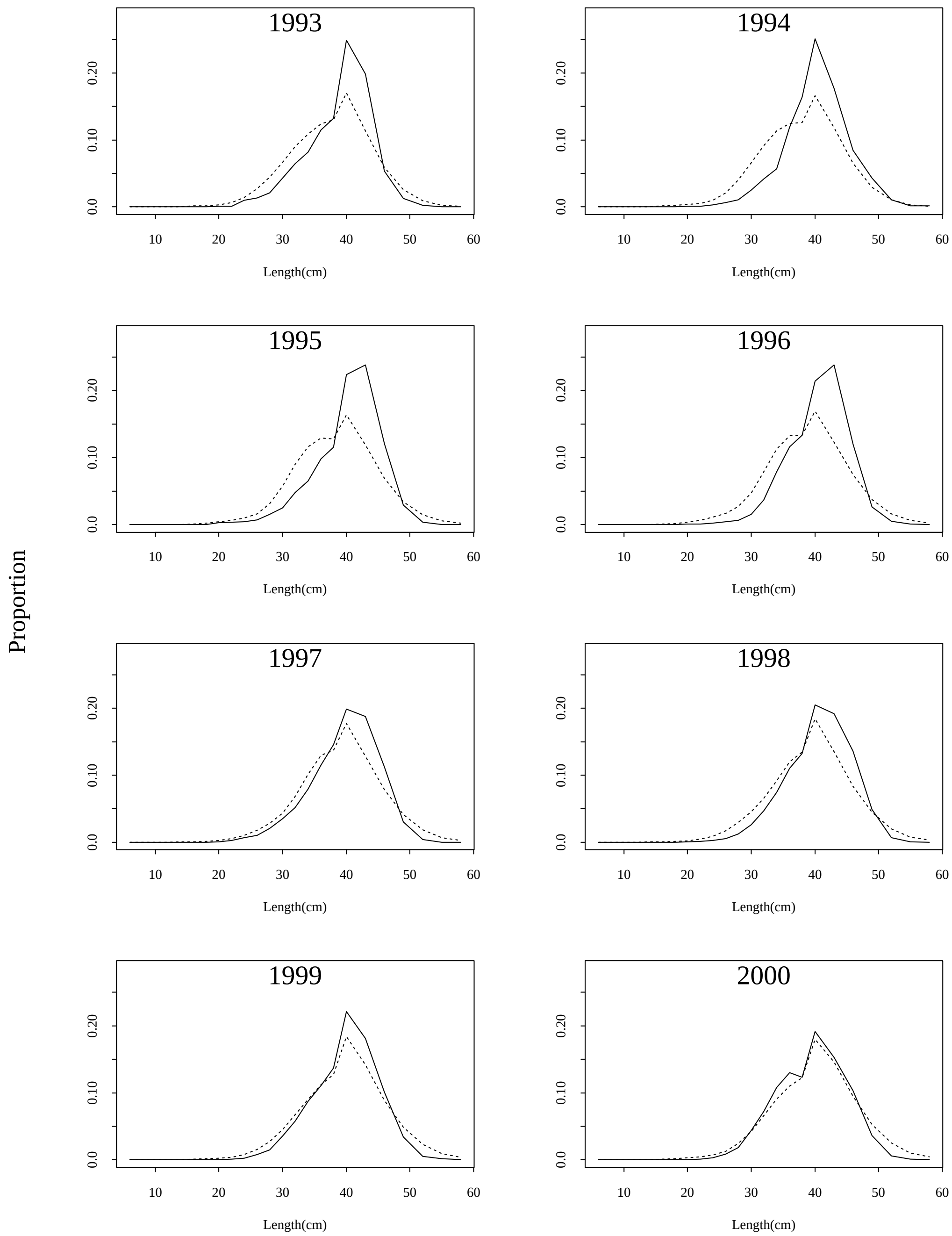
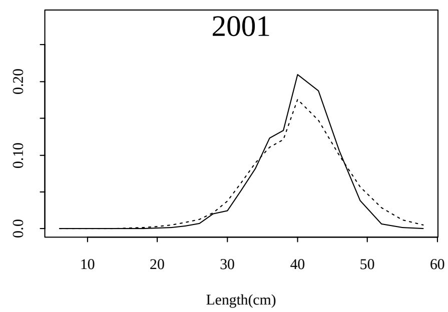


Figure 8. Female fishery length composition by year (solid line = observed, dotted line = predicted)



Proportion

Figure 8. Female fishery length composition by year (solid line = observed, dotted line = predicted)

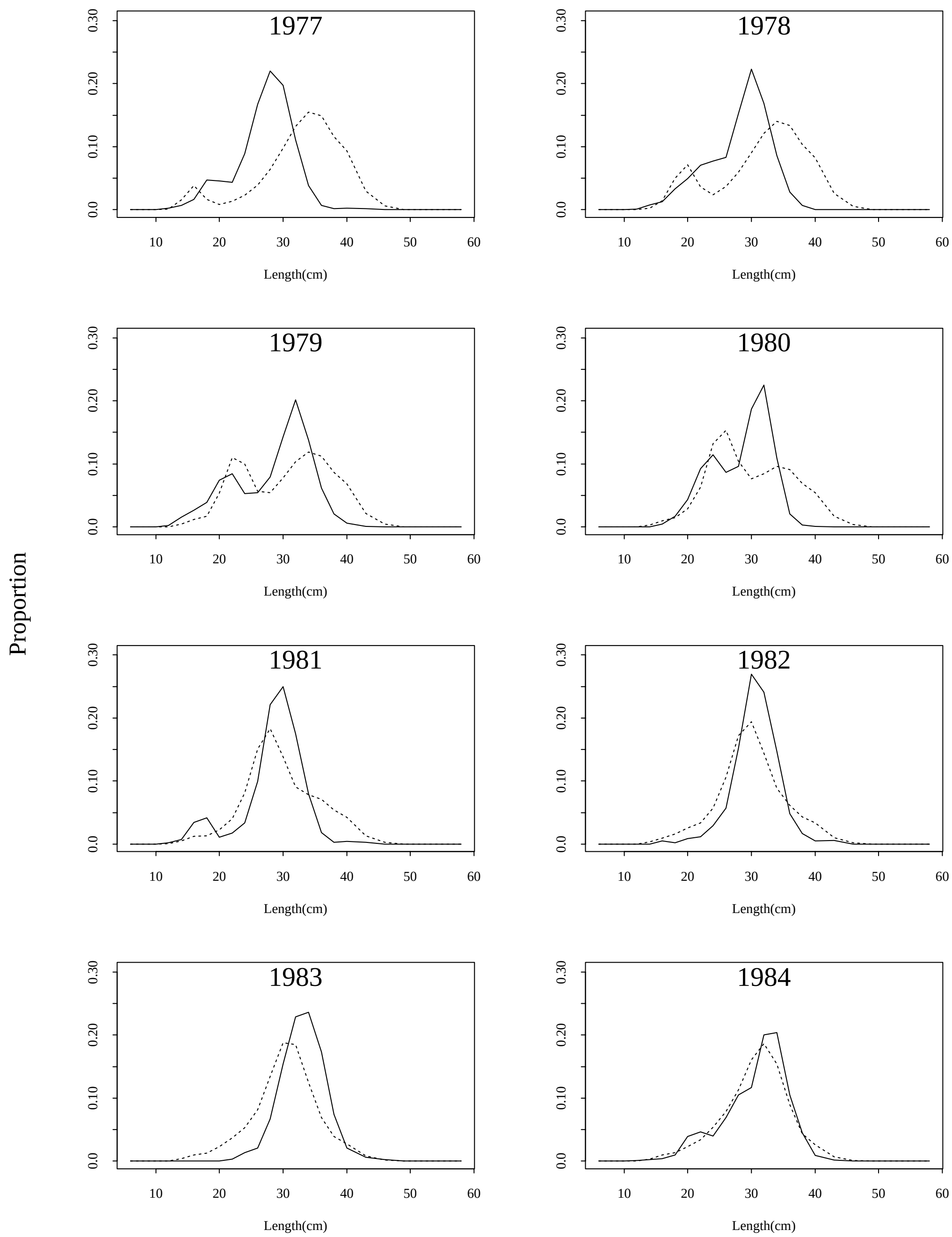


Figure 9. Male fishery length composition by year (solid line = observed, dotted line = predicted)

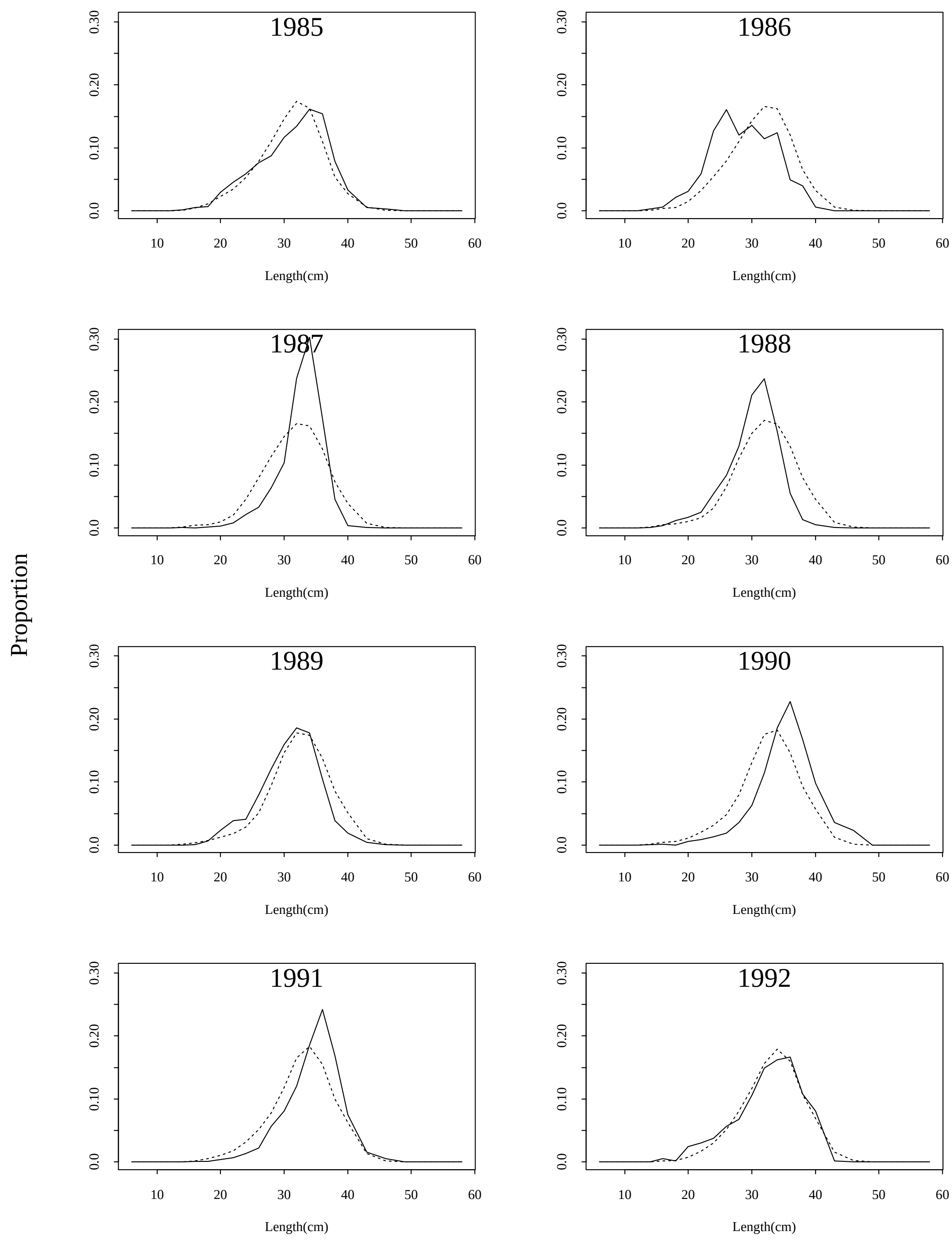


Figure 9. Male fishery length composition by year (solid line = observed, dotted line = predicted)

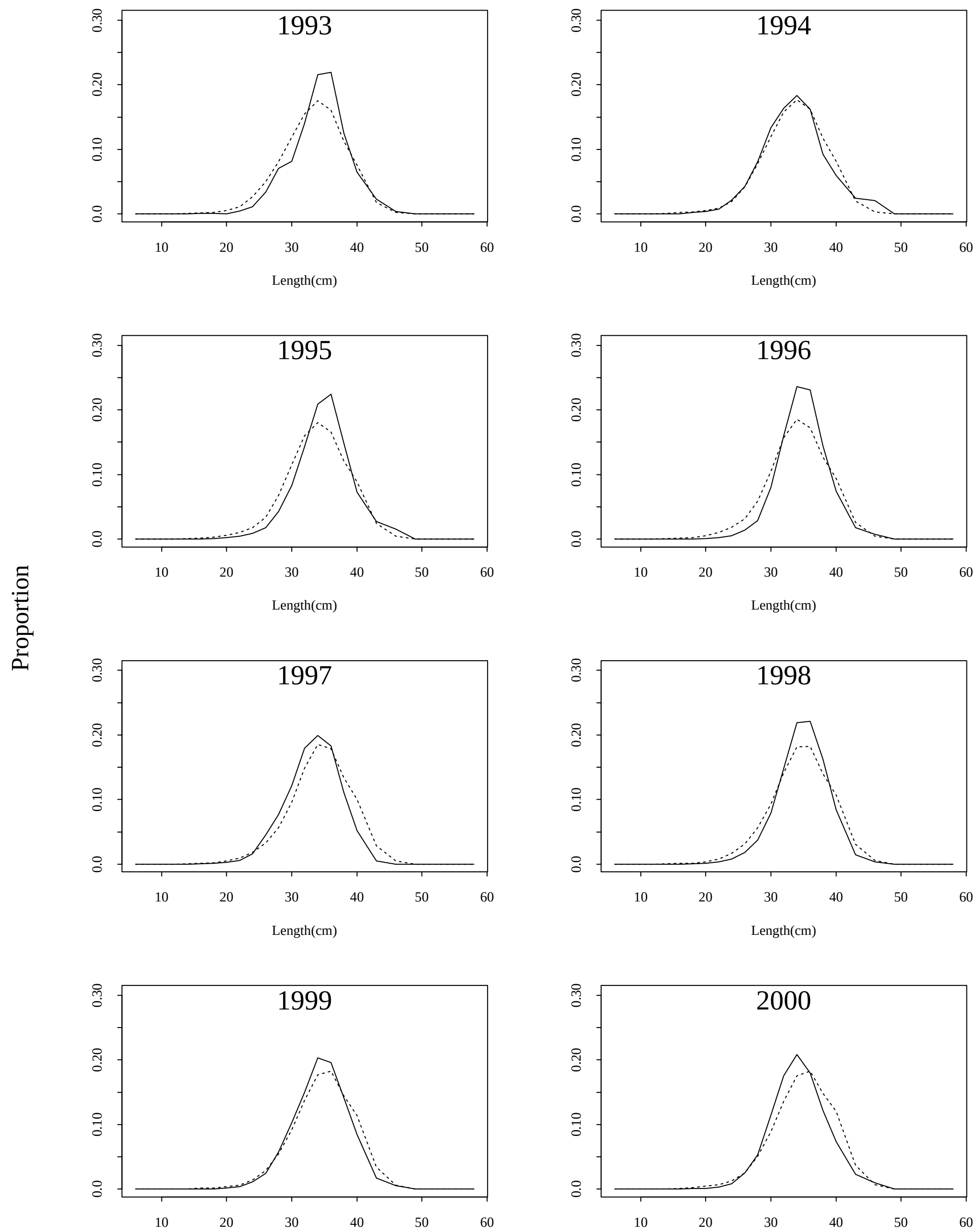


Figure 9. Male fishery length composition by year (solid line = observed, dotted line = predicted)

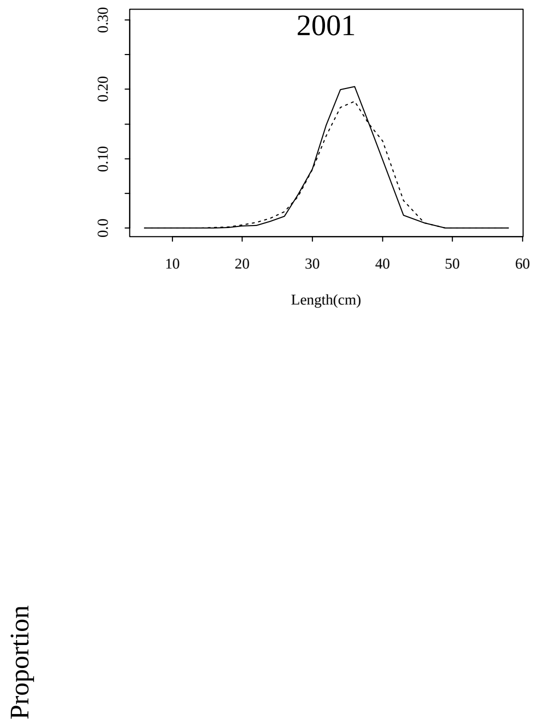


Figure 9. Male fishery length composition by year (solid line = observed, dotted line = predicted)

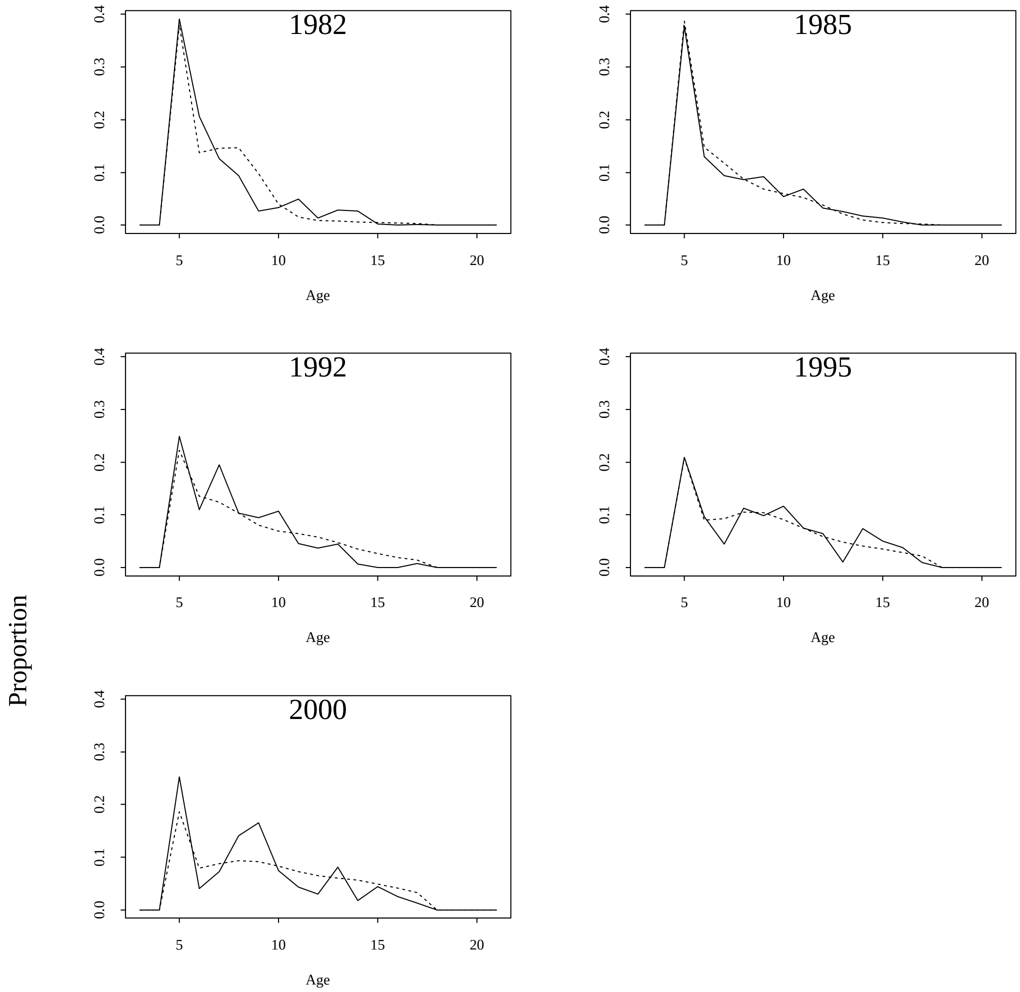


Figure 10. Survey male age composition by year (solid line = observed, dotted line = predicted)

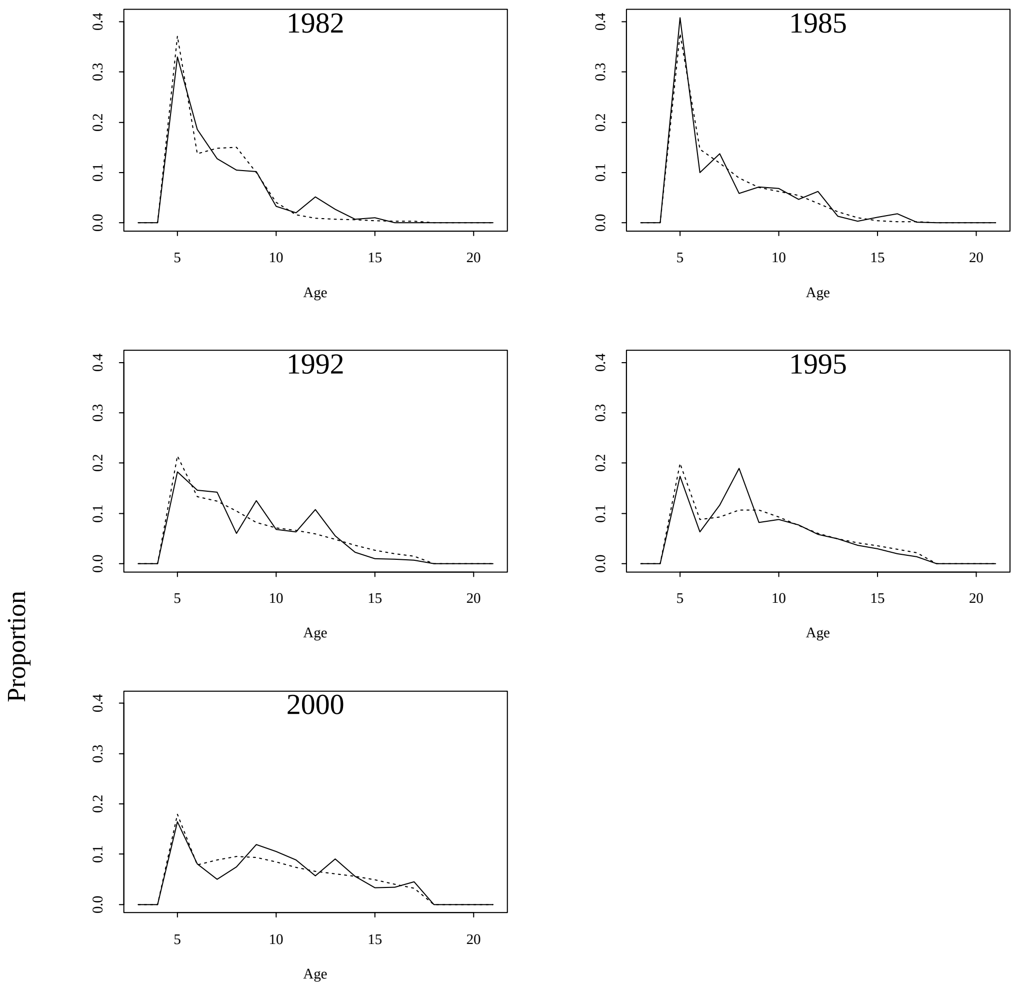


Figure 11. Survey female age composition by year (solid line = observed, dotted line = predicted)

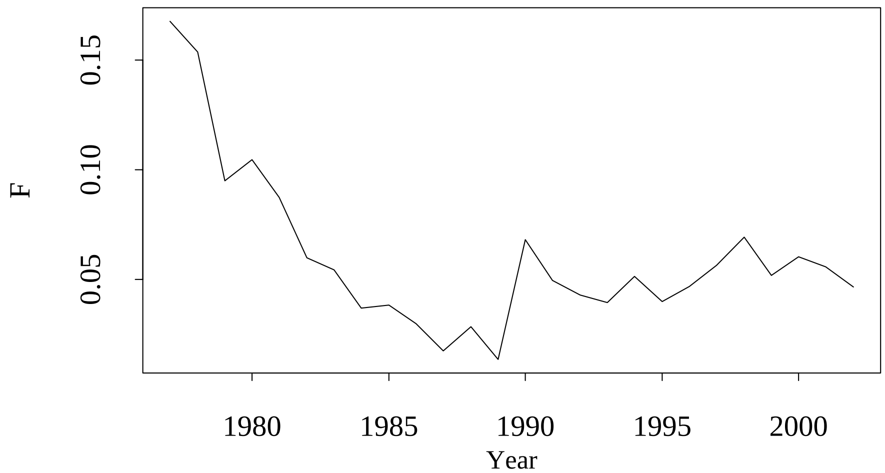


Figure 12. Estimated fishing mortality rate of flathead sole

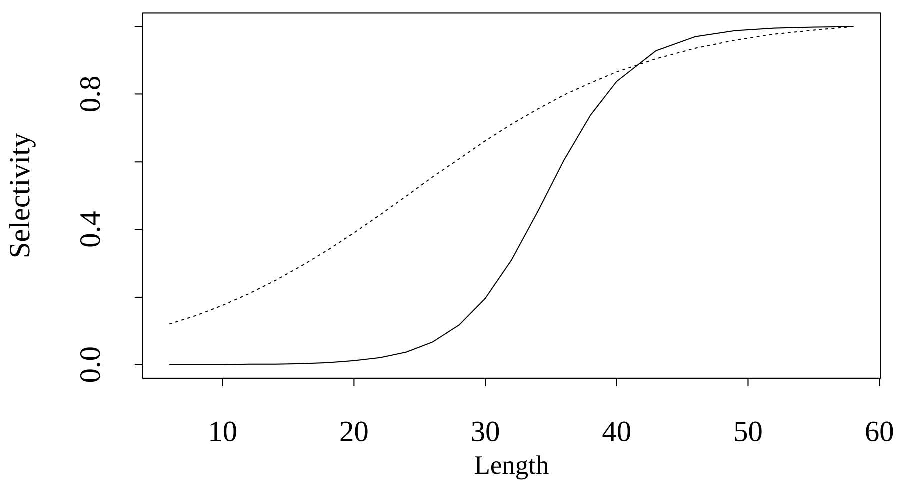


Figure 13. Estimated fishery (solid line) and survey (dashed line) selectivity curve by length

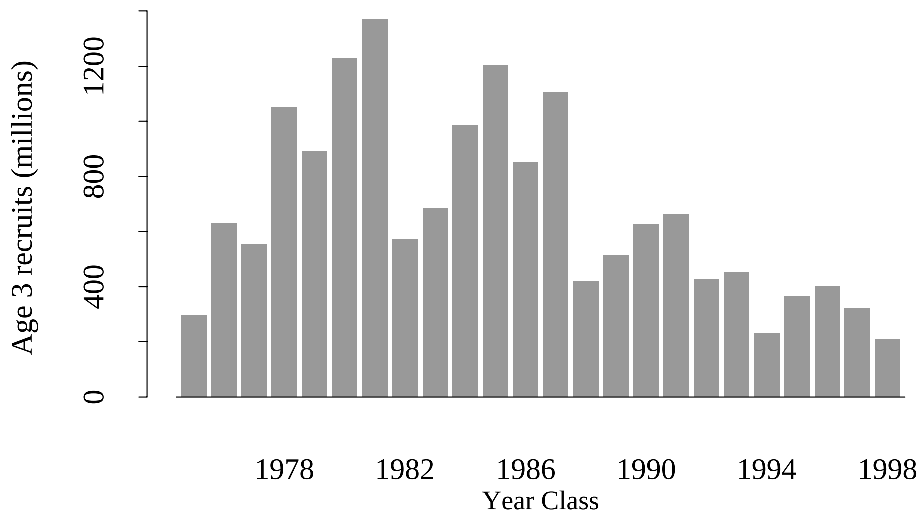


Figure 14. Estimated recruitment (age 3) of flathead sole

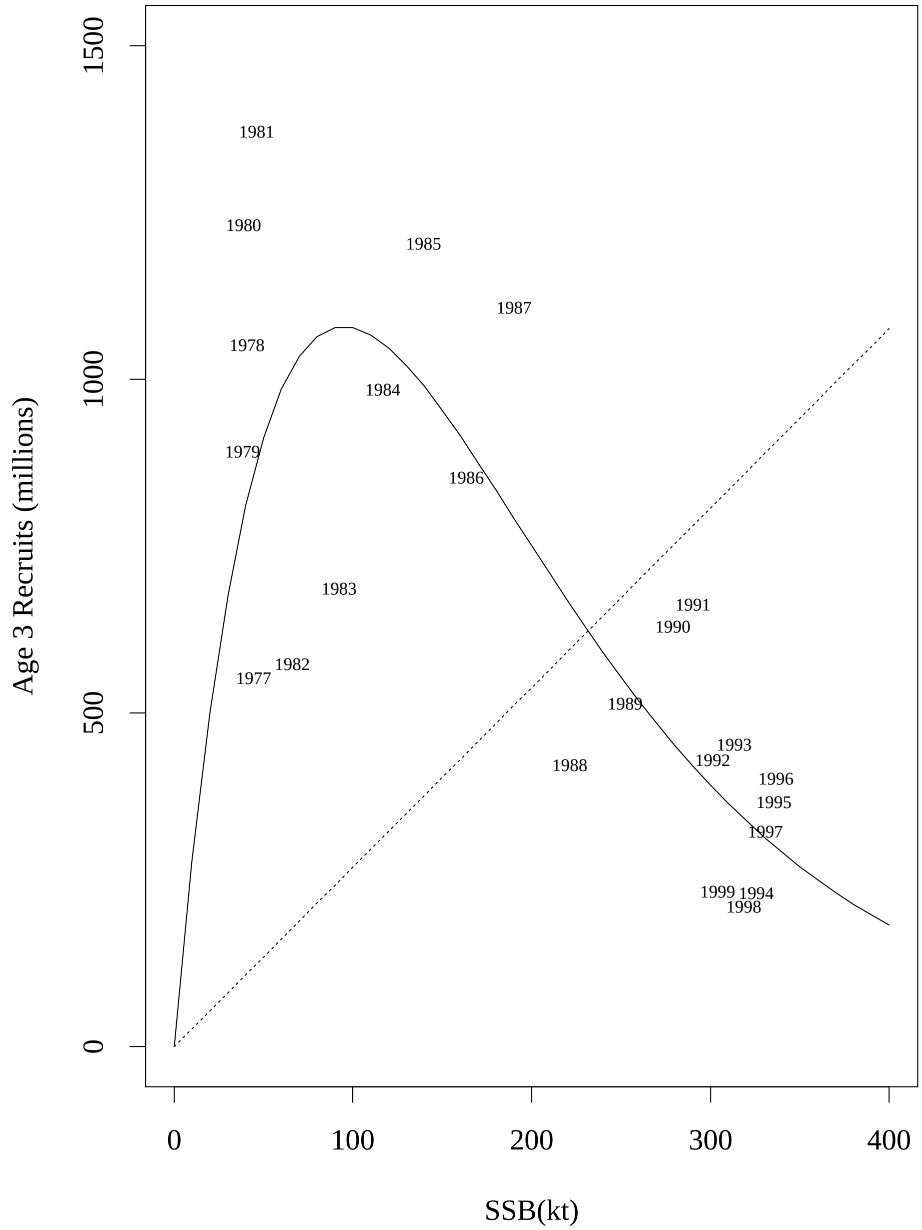
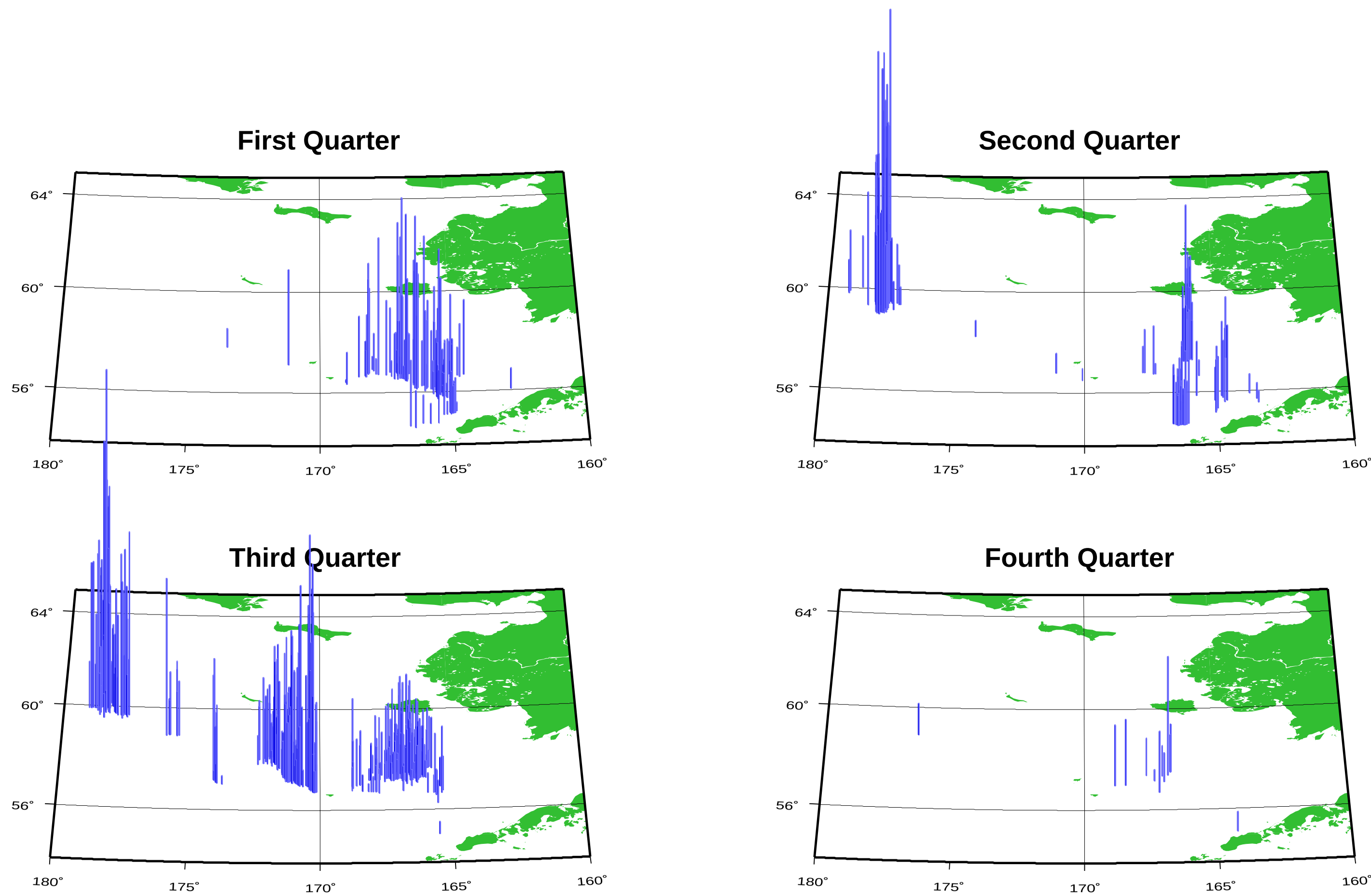


Figure 15. Estimated female SSB and recruitment of flathead sole, labeled by year class, with a fitted Ricker curve (solid line).
The replacement line is based on an F40% value of 0.29



Appendix Figure 1. Flathead sole fishery catch (relative biomass), by quarter, of hauls where more than 20 percent of the catch was flathead sole.